MARINE NAVIGATION AND SAFETY OF SEA TRANSPORTATION

EDITOR: ADAM WEINTRIT

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Marine Navigation and Safety of Sea Transportation

Editor

Adam Weintrit
Gdynia Maritime University, Gdynia, Poland

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

Table of Contents

Chapter 5. Navigational tools, systems and equipment

Chapter 6. Anti-collision

Chapter 12. Methods and algorithms

Chapter 13. Safety and reliability of technical systems

Chapter 14. Marine transportation

Chapter 15. Human factors and crew resource management

Chapter 16. Maritime education and training

Chapter 17. Maritime policy, proposals and recommendations

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TransNav 2009 – Review of scientists and professionals meeting in the field of safety of navigation and sea transportation

Foreword to the Monograph

A. Weintrit & T. Neumann
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The paper presents background and preparation to the 8th International Navigational Symposium on Marine Navigation and Safety of Sea Transportation **Trans-Nav 2009**, organized jointly by the Faculty of Navigation, Gdynia Maritime University and the Nautical Institute, to be held from 17 to 19 June, 2009 in Gdynia, Poland. The Symposium is addressed to scientists and professionals in order to share their expert knowledge, experience and research results concerning all aspects of navigation, safety at sea and marine transportation.

1 INTRODUCTION

In today's world, in addition to meeting high standards of safety, environmental protection and efficiency, the international maritime industry has to meet the demands of enhanced security. The general theme of the Navigational Symposium: "Marine Navigation and Safety of Sea Transportation" is, therefore, most timely as it provides participating distinguished delegates who represented Maritime Education and Training (MET) and research institutions, shipping industry, navy, shipowners, classification societies, maritime administrations, hydrographic offices, ports, services, professional institutes, maritime transportation agencies, societies and navigational instrument manufacturers.

When Symposium on Navigation met for the first time in 1995, one of its highest priorities was "to promote last research in the field of Navigation".

What could be more relevant, therefore, than representatives from 37 countries all over the world coming together to discuss the best possible ways of preparing staff at sea, in shipping companies, ports and maritime administrations to meet these challenges? Hosted by the Gdynia Maritime University there could be no better forum for stimulating interesting and fruitful contributions to discussion of maritime safety issues and for development strategies to address them through maritime education and training.

If we are to uphold and improve standards and ensure continued vigilance, nothing could be of greater importance than the training of the maritime professionals of the future. The papers presented at the **TransNav'2009** cover a full range of topics, from operations, management and organization to engineering and sciences. This Monograph is a set to become a source of inspiration and reference for maritime institutions worldwide and it is of relevance to all who are involved in the maritime industry, especially in maritime **Trans**port and **Nav**igation.

Our imagination on positioning and location is never ending. New techniques and ideas are coming. There are so many radio signals and information infrastructures for positioning around us. Seamless and ubiquitous positioning will point and guide you wherever you are and wherever you go. It all depends on our commitment.

2 MAIN TOPICS

The Symposium main topics are the following:

- Marine navigation,
- Safety and security of maritime shipping,
- Sea transport and transportation technology,
- Hydrography, geodesy and marine cartography,
- Geomatics and GIS in maritime applications,
- Electronic chart systems ECS and ECDIS,
- Inland, river and pilot navigation systems,
- Presentation of navigation-related information,
- Route planning and monitoring; passage plan,
- Integration of navigational systems, INS/IBS,
- E-Navigation,
- GPS, Glonass, Galileo, GNSS and radio based navigational systems,
- Telematics in marine transportation,
- Automation aspects in navigation,
- Algorithms and methods,
- Ships routeing and associated protected measures,
- Maritime traffic engineering,
- Systems of control, guidance and monitoring of traffic, VTS,
- Manoeuvrability and hydrodynamics of ships,
- Colregs, anti-collision, radar equipment, ARPA, AIS, LRIT, VDR,
- Decision support systems and Artificial Intelligence methods in maritime transport,
- Data transmission and processing,
- Modelling and numeric methods in maritime industry,

- Maritime search and rescue issues,
- Human factors, marine accidents, human errors,
- Crew resource management, safe manning, stress and fatigue,
- Navigational systems – the end user experience,
- Marine simulation; full mission bridge, navigational simulators,
- Meteorology and nautical oceanography,
- Standardization of navigational terminology,
- Maritime education and training; model courses validation.

3 HONORAY COMMITTEE

It is our pleasure to inform that the following very important persons have kindly accepted the honorary patronage of the Symposium:

- VAdm Alexandros Maratos, President of the International Hydrographic Bureau,
- Dr. Hisashi Yamamoto, Secretary of the IAMU (International Association of Maritime Universities),
- Capt. Anna Wypych-Namiotko, Under-Secretary in Ministry of Infrastructure of the Republic of Poland,
- Dr. Wojciech Szczurek, Mayor of Gdynia,
- Capt. Richard Coates, FNI, President of the Nautical Institute,
- Prof. Romuald Cwilewicz – Rector of the Gdynia Maritime University.

4 PROGRAMME COMMITTEE

There is a long list of Programme Committee members, more than one hundred names of distinguished persons in the field of Maritime Transport and Navigation from Poland, Europe and the rest of the world (31 different nationalities):

– Prof. Sauli Ahvenjarvi	FI
– Prof. Roland Akselsson	SE
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– Prof. Krzysztof Czaplewski	PL
– Mr. Eric Dawicki – President of NMI	US
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– Prof. Eamonn Doyle	IE
– Prof. Daniel Duda, Master Marines, PNS President	PL
– Prof. Janusz Dyduch	PL
– RAdm. Dr. Czeslaw Dyrcz	PL
– Prof. Ismail Deha Er	TR
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– Prof. Mieczyslaw Hann	PL
– Prof. Shogo Hayashi, Master Mariner	JP
– Prof. Guenter W. Hein	DE
– Prof.. Michal Holec	PL
– Prof. Kinzo Inoue	JP
– Prof. Kajetan Jackowski	PL
– Prof. Ales Janota	SK
– Prof. Jacek Januszewski	PL
– Prof. Tadeusz Jastrzebski	PL
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– Prof. Yongxing Jin	CN
– Prof. Miroslaw Jurdzinski, Master Mariner, FNI	PL
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– Prof. Zhengjiang Liu	CN
– Prof. Miroslaw Luft	PL
– Prof. Zbigniew Lukasik	PL
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– Prof. Jin Wang UK
– Prof. Ryszard Wawruch, Master Mariner PL
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– Prof. Adam Weintrit, Master Mariner, FRIN, FNI PL
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– Prof. Adam Wolski, Master Mariner, MNI PL
– Prof. Hideo Yabuki, Master Mariner JP
– Prof. Homayoun Yousefi, MNI IR
– Capt. Ricardas Zazeckis, Master Mariner LT
– Prof. Janusz Zielinski PL

The Organizing Committee would like to express its gratitude to the Programme Committee members totally committed to papers review process. Thank you very much for your matter-of-fact critical comments, in general well received by the authors and taken into consideration in the last version of submitted papers.

5 ORGANIZING COMMITTEE

The Chairman of the TransNav'2009 Organizing Committee and the editor of Symposium Proceedings elaborated as Monograph titled "Advances in Navigation and Safety of Sea Transportation" is Prof. Adam Weintrit, Dean of the Faculty of Navigation GMU, Head of Department of Navigation and Chairman of Polish Branch of the Nautical Institute.

The Secretary of Symposium is Tomasz Neumann (DN, GMU).

The members of the Organizing Committee are the following:

– Andrzej Bomba, Chairman of Technical Committee (Technical Matters, Sponsors),
– Piotr Kopacz (Transport Logistics),
– Maria Lozinska (Translator/Interpreter),
– Hanna Pleger (Office, Correspondence, Funds),
– Dorota Rajmanska (Office, Registration),
– Magdalena Zuzelska (Accommodation).

6 TECHNICAL COMMITTEE

The Chairman of the Technical Committee is Andrzej Bomba, active member of Organizing Committee, responsible for advertisements and contact with the sponsors. There are the following members of the Technical Committee:

– Piotr Bobkiewicz
– Szymon Brzoska
– Piotr Kabzinski
– Dariusz Krucki
– Teresa Majer
– Ryszard Miszke
– Dorota Rajmanska
– Janusz Sawka
– Wojciech Stasiak
– Adam Uljasz.
– Magdalena Zuzelska

7 SYMPOSIUM PROCEEDINGS

Symposium Proceedings is organized thematically like a Monograph.

Each paper was reviewed at least by three members of the Programme Committee. Qualified papers submitted on time are published in the TransNav'2009 Proceedings. Some of them will be presented at plenary sessions, most on parallel thematic sessions and the rest on poster session. The authors were informed that the organizer reserves the right to qualify some papers for the poster session.

7.1 *Submission procedure*

After the receipt of information on paper qualification by the Programme Committee an electronic version of the paper in English was submitted at web site http://transnav.am.gdynia.pl or as an e-mail attachment. It was informed that the above material shall be with the Symposium Office before the deadline for submission (15th December). Any material received too late (after 15th February) is not published.

Special software designed by Tomasz Neumann to enable on-line registration, manage the abstracts and papers, communication with participants and authors was used in the process of selection of articles. It assists to send the requests to the Program Committee Members to carry out reviews, the information about the results of the review to the authors, information on the current status of article, etc.

All received papers were inserted to the paper submission system. The all papers had to be prepared strictly according to the editor instructions. Before papers have gone to the next stage of the articles selection process, format some of them was corrected by staff of Symposium Office.

Prepared papers in electronically way were send to at least three independent reviewers, specialists in the paper main topic. Average time of review the paper was about two weeks. After receiving at least two positive reviews from Program Committee Members, their comments, suggestions and proposals of changes the paper was sent back to the authors. Most of the authors agreed whit reviewers opinions and made minor alterations to the text. After an authors' revision, papers were placed into relevant chapter of the Monograph.

During the process of selection of articles the Symposium Office sent to the Program Committee Members more than 450 requests for enforcement reviews. In total, the Symposium Office received 328 reviews. 26 reviewers had to comply with a very heavy task – to review received more than 5 articles.

7.2 *Chapters of Monograph*

The Monograph is divided into seventeen following chapters:

- – Introduction
- – Chapter 1 Safety of Navigation
- – Chapter 2 Manoeuvring and Ship-Handling Simulation
- – Chapter 3 Global Navigation Satellite System
- – Chapter 4 Marine Traffic Control and Automatic Identification Systems
- – Chapter 5 Navigational Tools, Systems and Equipment
- – Chapter 6 Anti-Collision
- – Chapter 7 Communication at Sea
- – Chapter 8 Manoeuvring and Pilot Navigation
- – Chapter 9 Sea-River and Inland Navigation
- – Chapter 10 Route Planning and Weather Navigation
- – Chapter 11 Hydrometeorological Aspects
- – Chapter 12 Methods and Algorithms
- – Chapter 13 Safety and Reliability of Technical Systems
- – Chapter 14 Marine Transportation
- – Chapter 15 Human Factors and Crew Resource Management
- – Chapter 16 Maritime Education and Training
- – Chapter 17 Maritime Policy, Proposals and Recommendations

All papers have been evenly divided among chapters. Number of articles from each section are shown in table below.

Table 1. Number of articles in each chapter.

Chapter title	Number of articles
1. Safety of Navigation	8
2. Manoeuvring and Ship-Handling Simulation	8
3. Global Navigation Satellite System	8
4. Marine Traffic Control and Automatic Identification Systems	8
5. Navigational Tools, Systems and Equipment	9
6. Anti-Collision	9
7. Communication at Sea	7
8. Manoeuvring and Pilot Navigation	9
9. Sea-River and Inland Navigation	6
10. Route Planning and Weather Navigation	6
11. Hydrometeorological Aspects	8
12. Methods and Algorithms	9
13. Safety and Reliability of Technical Systems	8
14. Marine Transportation	9
15. Human Factors and Crew Resource Management	8
16. Maritime Education and Training	8
17. Maritime Policy, Proposals and Recommendations	8

7.3 *Round Table Panel*

On 17th of June (Wednesday) – the First Day of Symposium – the Round Table Panel Discussion will be organized under chairmanship of Prof. Vidal Ashkenazi, UK. The title of Round Table Plenary Session is "*GNSS and Safety & Security of Marine Navigation*".

8 THE HISTORY OF OUR MEETINGS

The Navigational Symposium is organized since 1995. It was initiative of the then Dean of the Faculty of Navigation Prof. Michal Holec.

In the eight previous symposiums more than 500 authors presented more than 500 papers:

- 1st Navigational Symposium: 46 papers (45 in Polish and 1 in English) and 61 authors representing 13 institutions,

Table 2. Round Table Panel Session.

Title *"GNSS and Safety & Security of Marine Navigation"*

Chair: Prof. Vidal Ashkenazi
Chief Executive Nottingham Scientific Ltd., UK

Panellists:

Prof. Dr. Christoph Guenther
Head of the Institute of Communications and Navigation, German Aerospace Center, Oberpfaffenhofen, Germany
Stig Erik Christiansen
GNSS Product Manager, Kongsberg Seatex AS, Norway
Sr. Jesus Carbajosa Menendez
President, Spanish Institute of Navigation, Spain
Capt. Edwin Thiedeman
Commanding Officer, US Coast Guard (USGS) Navigation Centre
Gian-Gherardo Calini
Head of Market Development Department, Galileo Supervisory Authority (GSA)
Prof. Dr. Adam Weintrit
Dean of the Faculty of Navigation, Gdynia Maritime University, Poland

Figure 1. The 1st Navigational Symposium organized by the Faculty of Navigation GMU in 1995.

– 2nd Navigational Symposium: 33 papers (31 in Polish and 2 in English) and 45 authors representing 14 institutions,
– 3rd Navigational Symposium: 56 papers (53 in Polish and 3 in English) and 64 authors representing 12 institutions,
– 4th Navigational Symposium: 54 papers (46 in Polish, 7 in English and 1 in Russian) and 75 authors representing 16 institutions,
– 5th Navigational Symposium on Marine Navigation and Safety of Sea Transportation: 35 papers (33 in Polish and 2 in English) and 33 authors representing 5 institutions,
– 6th International Navigational Symposium on Marine Navigation and Safety of Sea Transportation: 69 papers (18 in English, and 41 in Polish) and 103 authors representing 23 institutions,

Figure 2. The 3rd Navigational Symposium organized by the Faculty of Navigation GMU in 1999. In the meddle the then Dean Dr Andrzej Niewiak.

Figure 3. The 4th Navigational Symposium organized by the Faculty of Navigation GMU in 2001.

Figure 4. The 5th International Navigational Symposium organized by the Faculty of Navigation GMU in 2003.

– 7th International Symposium TransNav 2007 on Marine Navigation and Safety of Sea Transportation: 133 papers (all in English) and 232 authors representing 66 institutions, including 51 came from abroad,

Figure 5. The 6th International Symposium on Marine Navigation and Safety of Sea Transportation organized jointly by the Faculty of Navigation and the Nautical Institute in 2005.

Figure 6. The 7th International Symposium **TransNav 2007** on Marine Navigation and Safety of Sea Transportation.

– 8th International Symposium TransNav 2009 on Marine Navigation and Safety of Sea Transportation: 133 papers (all in English) and 245 authors from 31 countries around the world, 86 representing Poland, 18 – China, 12 – Norway, 11 – Japan, 10 – Philippines, 9 – Turkey, 8 – Germany, 7 – Romania, Slovakia and Lithuania, 6 – United States and Ukraine, 5 – Spain, Korea and United Kingdom, 4 – Belgium and Sweden, 3 – Canada, Finland, Czech Republic, Georgia and Bulgaria, 2 – France, Greece, Italy and Malaysia, 1 – Iran, Ireland, Pakistan and Vietnam.

The first our international guest was Adam J. Kerr, director of the International Hydrographic Bureau, Monaco (1997). Till now the most active internationals are: Ismail Deha Er (Turkey), Melchor Magramo (Philippines) – authors of six presented papers and Prof. Chaojian Shi (China), Dr. Qinyou Hu (China) – authors of five presented papers.

9 CONCLUSIONS

As we all know the maritime transport plays a special role in the world economy. It is not only a question of its share in international trade but also an ecological issue. Statistical data indicate that this form of transport has the least adverse impact on the environment and is a minor source of environmental pollution as compared to land-based activity.

It is a great honour and pleasure of the Faculty of Navigation, Gdynia Maritime University in association with the Nautical Institute to host this year's Symposium and to invite scientists, theoretical and practical navigators, manufacturers, service providers, design engineers and representatives of national and international organizations, agencies and societies to meet the navigation community in Gdynia, Poland.

The 8th Symposium is accompanied by a small exhibition, which will display the latest developments in on-board equipment, education and training, safety and navigation infrastructure, and navigation technologies and equipment.

We would like to express our gratitude to distinguished session's chairmen, speakers, exhibitors, sponsors, participants and all members of Honorary, Programme, Organizing and Technical Committee for their great contribution for expected success of the 8th International Symposium on Navigation **TransNav 2009**. We congratulate the authors for their work.

Seven such meetings were already held. This monograph is a collection of 133 various papers of the 8th International Symposium TransNav'2009. We hope that you can find something captivating and inspiring for you. We wish all the participants of our symposium much intellectual pleasure and we hope that the ideas and subjects we may work out today will serve maritime companies in their daily practice.

Dear reader, today we would like to invite you to participate in the next edition of the International Symposium on Navigation **TransNav** which will be held in Gdynia in June 2011.

http://transnav.am.gdynia.pl

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List of reviewers

Scientific Committee (rewriters):

Prof. Sauli **Ahvenjarvi,** Satakunta Polytechnic, Rauma, Finland
Prof. Roland **Akselsson**, Lund University, Sweden
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Prof. Wieslaw **Galor**, Maritime University of Szczecin, Poland
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Hydrographic Office Of The Polish Navy
Polish Academy of Science, Committee of Transport, Traffic Control Section
Polish Academy of Science, Committee of Geodesy, Section of Navigation and Hydrography
Polish Navigation Forum
Polish Nautological Society

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Message from The President of The Nautical Institute

Opening Address for TransNav'09 at Gdynia Maritime University

The Nautical Institute congratulates its Poland Branch members for pro-actively working together with the Gdynia Maritime University to organise this impressive Conference. The issues facing the maritime industry today are certainly no fewer than those that drove the Founding Members to form The Nautical Institute back in 1971 so the need for our members to work with other professionals from diverse sectors to address issues facing the industry is as important as ever. Indeed the tasks and regulations with which today's mariners have to cope are even more complex and extensive. Evidence of this complexity can be seen in many different ways:

- The increase in technology aboard ship with integrated bridge and navigation systems being fitted in many more ships whilst others continue to have to cope with an array of stand-alone equipment.
- The mandatory carriage of ECDIS from 2012, requiring the transition from the use of paper charts.
- The increase in alarm systems, each of which is designed to help the mariner, but which may actually distract and confuse the watchkeeper.
- The increase in the regulatory burden which can be accurately measured by the doubling in size and content of the 2nd Edition of the Institute's publication "The Shipmaster's Business Companion" in just six years and the 3rd Edition is already being prepared to keep pace with further regulatory change.
- The development of the E-Navigation concept aimed at integrating ship and shoreside navigation systems so as to improve shipping safety.
- Changes in manning and management practices over the years, some detrimental to safety whilst others have had a positive effect.
- The shortage of experienced and competent watchkeeping officers worldwide which is forecast to worsen despite the deepening recession that we are suffering at this time.

Many of these changes, such as the ISM Code, have had a positive effect on the safety and efficiency of shipping but all change needs to be managed in a thoughtful and properly planned manner. This requires leadership and ensuring that those affected by the change understand it and have a constructive input into it. In this way, the change will be made more effective. The Nautical Institute continues to play an important part in this process of change and constructively questions particular proposals, practices, or regulations where we feel it is professionally necessary to do so. The branches have a major role in this process on both an international and local level and working with the maritime universities and colleges is essential in ensuring that future generations of seafarers are properly educated and trained for their responsible and demanding role of providing a safe, efficient and environmentally friendly shipping service.

The Council of The Nautical Institute and the Secretariat will continue to work closely with the Poland Branch and Gdynia Maritime University in helping to resolve the professional issues of today and the future so as to promote and develop high standards of education and training. It is indeed impressive that over 130 Papers have been received for this Conference on a wide range of relevant issues, and I am aware that they are of a high quality. I congratulate the authors for the work they have put in and I am delighted to be here to hear the best presented.

It is also my pleasure to present in person the Certificate of Fellowship of The Nautical Institute to Professor Captain Adam Weintrit following his election to this highest membership status last December. His Fellowship is deserved recognition of the very significant contributions he is making to both nautical science, through the research, teaching and practice of navigation, and the formation and development of the Institute's Poland Branch. Our branch network is fundamentally important in terms of recruitment and retention of members as well as for input to the professional work of the Institute, and dynamic leadership is essential to sustain this work. Adam provides this here in Poland and we are highly appreciative of his efforts.

The President of The Nautical Institute
Captain Richard Coates, FNI

Captain Richard Coates, FNI
President
The Nautical Institute

Captain Coates is currently the Operations Manager of Humber Sea Terminal and is a former 1st Class Pilot for the Humber. His sea-going career saw him serving from Cadet to Master in a wide variety of vessels including passenger, general cargo, container, coasters, dry bulk, offshore and chemical tankers. His experience also includes work as a consultant and surveyor.

He served on Council from 1990 to 1996 and was elected as a Vice President in 2002. He also served on Council's Membership Committee from 1995 and has been its Chairman for the past 6 years. A previous Chairman of the Humber Branch, Richard is an Elder Brother of the Newcastle Trinity House, and is a past Chairman of the British Maritime Pilots Association.

Elected President of The Nautical Institute on 12th June 2008, Captain Coates said:

"I believe that the President of The Nautical Institute needs to be able to devote the time, and call upon sufficient resources, in order to continue the implementation of the activities and business plans identified by Council in the 2006–2010 Strategic Plan. In addition, I would seek to encourage the continued 'internationalisation' of our Institute, and to encourage the recruitment of younger members by such means as ensuring that the Ships' Officers Publication is realised, promoting Continued Professional Development, and ensuring that all members are aware of the success which the N.I. enjoys when engaging with decision making bodies."

Chapter 1. Safety of navigation

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

1.1 The present and expected changes in maritime safety, security and defense functions

J. Urbański, W. Morgaś & M. Mięsikowski
Polish Naval Academy, Gdynia, Poland

ABSTRACT: In this paper, an attempt has been made to present the subject and state of the three main functions of each maritime country; these are: the maritime safety, maritime security and maritime defense functions. There have been also discussed the subjects of these functions as well as the reasons and process of the closest and closest cooperation between these functions, and even the merger of these functions in one maritime function, i.e. in the maritime safety, security and defense functions. Especially quickly proceeds the merger of the maritime security and maritime defense functions in one maritime function, i.e. in maritime security and defense function

1 INTRODUCTION

Each maritime country have to realize three main maritime functions, these are:

– maritime safety;
– maritime security;
– maritime defence.

Maritime safety is the safety of life and property at sea from the environmental and operational threats, as well as the safety of maritime environment from pollution by the ships. On the national level the maritime safety is being achieved as the result of the existing maritime safety legal framework; operating the global and regional navigational infrastructure, but mainly as the result of operation of the highly specialized maritime operational services. Each maritime country possess not less then 10 different kinds of maritime operational services. Most important of them are the following:

– ships classification, survey, certification and inspection services;
– aids to navigation service;
– hydrography and navigational information service;
– search and rescue (SAR) service;
– marine environment protection service;
– combating the environmental pollutions service;
– Vessel Traffic Services (VTSs);
– ensuring the security of the ships and port facilities service, etc.

The maritime security is the security from the terrorism, piracy and similar threats, as well as effective interdiction of all the illicit activities on sea such as pollution of the marine environment; illegal exploitation of sea resources; illegal immigration; smuggling the drugs, persons, weapons and other matters that can be used for terrorist activities. The maritime security is achieved mainly as the result of the operation of the proper national maritime services such as: Coast Guard, maritime police, Customs services, Immigration services and some other [Dyrcz, 2005], [Jones, 2006], [Walczak, 2004].

It should be added that in this paper the term "Coast Guard" means the national maritime security service responsible for realization of the maritime security function. However, these services only in the United States and Canada are named as Coast Guard [www.uscg.mil.]. In the Member States of the EU, there exist different names of the national maritime security services, such as: Border Guard, Maritime Police, Maritime and Coast Guard Agency (MCA) [www.mcga.gov.uk.] and many others. Also the scope of tasks that realize these services differ considerably in the each particular Member States of the EU. The above is the result of the historical tradition of the development of these services. The European Union considers that the above situation is not favorable for the closer cooperation of the security services of the Member States of the EU. Therefore, the European Union tries to unify these services, i.e. to unify not only their names but also the scopes of the competences of these services. [ec.europe.eu/maritime_affairs.]

The maritime defense is the constituting part of the national military defense. Maritime defense for the Member States of the EU is the defense of national territorial integrity; defense of the sea lines of communication and other national maritime assets; contribute to the peace and security in the different world's areas; and assists the national security services in the crisis and distress situations. Ensuring the maritime defense is the main objective of naval forces [NSA, 2002]. These forces include the different kinds of combat ships and craft, aircraft, as well as the Autonomous Air Vehicles (UAV) and Autonomous Underwater Vehicles (UUV), and others.

In the not distant past the above mentioned functions, i.e. maritime safety, maritime security and maritime defense functions were realized by the organizational structures (maritime operational services: Coast Guard and Navy) that operated absolutely separately. They, of course, assisted each other but only in the very difficult situations.

However now, but more precisely, in some last years, the above mentioned situation began to change. These changes express themselves in the new situation of the national maritime services. The main national operational services, i.e. the Coast Guard and Navy, have been constrained to cooperate closer and closer, and even they have begun to realize the tasks that constituted not their own functions. The most characteristics function in this respect is the maritime security functions that besides the Coast Guard or similar services, has begun to be realized also by the navy and other maritime operational services.

The main reason, and at the same time the turning point of the above changes was the outbreak of the Global War on World Terrorism (SEP of 11th, 2001).

The above process of closer and closer cooperation of the main national maritime services did not cease to exist but it continues to develop and becomes more and more important.

Taking the above situation into consideration the conclusion can be drawn that besides the global threat of terrorism, there must exist also some other important reasons that result in the stepwise integration of the maritime safety, maritime security and maritime defence functions in a kind of the new super function, i.e. in the integrated function of maritime safety, security and defence [Kopacz, 2004], [Kopacz, 2005], [Kopacz, 2006].

Below, there are presented the following issues:

- reasons of the present changes in the main national maritime functions;
- present state of the maritime safety, security and defence functions;
- expected changes in the maritime safety, security and defence functions.

2 THE REASONS OF THE PRESENT CHANGES IN THE MAIN NATIONAL MARITIME FUNCTIONS

The main changes in the maritime safety, security and defense functions express themselves mainly in the following situation:

- maritime security tasks that in the past were realized by the Coast Guard or similar security services, there are being now, in higher and higher degree, realized also by the two other services, i.e. by the national operational services and by the navy,
- the tasks of the maritime defence that in the past were almost exclusively realized by the navy, are now being realized, in higher and higher degree, by the other maritime services, i.e. by the national operational services and by the Coast Guard (or similar security services), however mainly by the last ones.

It should be also mentioned that the issues of maritime safety begin to be the exclusive issues of national operational services and begin to be also the issues of two other main maritime services, i.e. Coast Guard and Navy. It is the result of the permanent growth of danger of pollution of marine environment by the ships, and the necessity of prevention such pollution, as well as combating the consequences of pollutions if they occurred.

The main reason of the above mentioned changes in the maritime safety, security and defense functions is not only the outbreak of the maritime terrorism in the world's dimension. This factor is of course the decisive factor of the changes being now underway. However, the outbreak of world's terrorism has also in high degree intensified the influence of many other factors of the present changes in the main maritime functions. These factors have the economic, political, military and social character, and have come into existence long before the outbreak of Global War on World Terrorism. Below we will try to enumerate the most important factors of the present changes in maritime safety, security and defense functions.

Collapse of the Soviet Military Block and coming into being the multipolar world with its religious, ethnic, national and other conflicts. The collapse of this military block resulted also in very considerable decreasing the probability of the military conflicts between maritime countries. Decreasing the probability of outbreak of the military conflicts between different countries results also from many other reasons that they will be discussed below.

"Further polarization between the world of the wealth" and the "world of the destitution". This process generates also the very unstable geographical regions in the respect of maritime security. In these regions exists very high level of terrorist attacks' threat, piracy threats as well as threat of ships capturing and their abduction. To the region of very high security risk belongs now such region as Persian Gulf, Arabian Sea, areas of Indian Ocean off the Horn of Africa (Somali's coast). The Gulf of Guinea (Africa's West Coast) [Peterson, 2007]. The high risk of piracy attacks exists also on the approaches to Malacca Strait and on the South China Sea.

Fast growing the new economic, political, military and social world's regions, such as the European Union, China, India and Brazil, very fast change the world situations that existed before. These new world's geographical regions result also in the decreasing the role of the United States not only in the economic aspect but also in the political and military aspects. The United States are loosing also stepwise their role as the world's military and sea power.

The further fast process of globalization express itself also in the very fast growing the international commerce, and in transportation by sea. The world economy is tightly interconnected. Over the past four decades, total sea borne trade has more than quadrupled. 90% of the world trade and two-thirds of its petroleum are transported by sea. The sea-lanes and supporting shore infrastructure are the lifelines of the modern global economy. They are visible but very vulnerable symbols of the modern distribution strategy [www.navy.mil/maritime/ Maritime_Strategy].

Process of climate change results also in the ecological and social disasters. Hence, the necessity of development crisis response capabilities to response to these kinds of maritime calamities.

Very fast progress of science and technologies, especially in such technologies as global positioning and global communication technologies and many other information technologies, is very favorable for ensuring the maritime safety and security but it also facilitates the terrorist activities. This progress facilitates also proliferation of nuclear weapon as well as other kinds of weapons of mass destruction (WMD) that can become also the weapons of terrorists.

3 PRESENT STATE OF THE MARITIME SAFETY, SECURITY AND DEFENSE FUNCTIONS

For the Member States of the European Union the main criterion of the distribution of the areas of realization of the maritime safety, security and defense functions between the main maritime services, constitutes the geographical location of the realization areas towards the own coast:

- in the areas close to the own coast, the functions of the maritime security and maritime defence have been realized by the Coast Guard and other security services, and Navy;
- in the areas located far from the own coast, the functions of the maritime security and maritime defence have been realized by the naval forces, mainly in the form of the maritime security operations (cf. CTF – 150) [en.wikipedia.org/wiki/Maritime_Security_Operations], [en.wikipedia.org/wiki/Combat_Task_Force_150].

However, as it was already mentioned, the above principle regards mainly the maritime countries of EU and maritime countries being the members of NATO. However, it can be also assumed that the above principle regard also the United States and their main maritime forces, i.e. Marine Corps, Navy and Coast Guard [www.navy.mil/maritime/Maritime_Strategy].

The maritime safety function in European Union and in its Member States is being realized on the three levels of maritime safety management [Kopacz, 2001], [Kopacz, 2006]:

- the first and the highest level of management constitutes the International Maritime Organization. It creates the legal and operational basis for maritime safety and security of the whole shipping industry;
- the middle level of maritime safety management constitutes the Vessel Traffic Monitoring and Information System (VTMIS) of the European Union. Main objective of such System is to considerably increase the maritime environment protection from pollution by ships and enhance the level of maritime security on the sea areas of the European Union [Urbański, 2007];
- the lowest, i.e. the national level of maritime safety management constitutes the network of the maritime operational services.

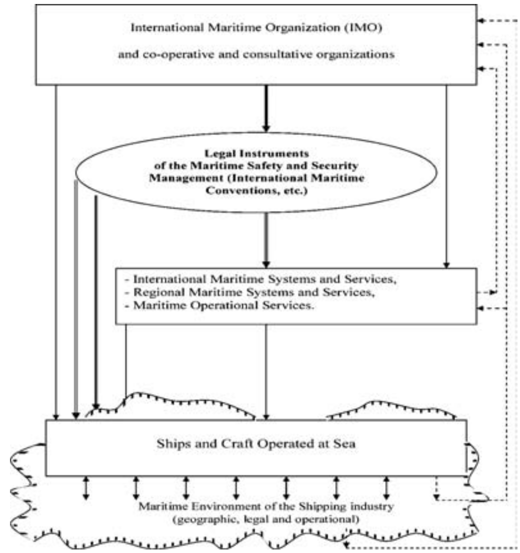

Figure 1. Institutions, legal instruments, systems and services of the maritime safety function.

In Figure 1, there are shown the institution, legal instruments, systems and services that realize the maritime safety function.

The maritime security function is not the new main maritime function. However, the importance of this function, i.e. the amount of its tasks and the significance of these tasks of this function have grown incomparable after the 11th of SEP, 2001. This function, as was already mentioned, is being realized now by all the three main maritime services, i.e. by the maritime operational services, Coast Guard and Navies. There exist two main kinds of geographical areas in which this function is being realized. First kinds of areas constitute the maritime areas of each Member State of the EU. The second kinds of areas are the far-away areas where exist very high risk for maritime security. In the first kind of maritime areas the maritime security function is being realized by the Coast Guards and Navies of the Member States of the EU. In the second kind of areas the maritime security function is being realized mainly by the navies of maritime states operating in these areas, mainly in the form of Maritime Security Operations conducted by the maritime NATO forces or the EU forces.

It should be added that in the relation to the shipping industry the maritime security function constitutes together with maritime safety function one compound

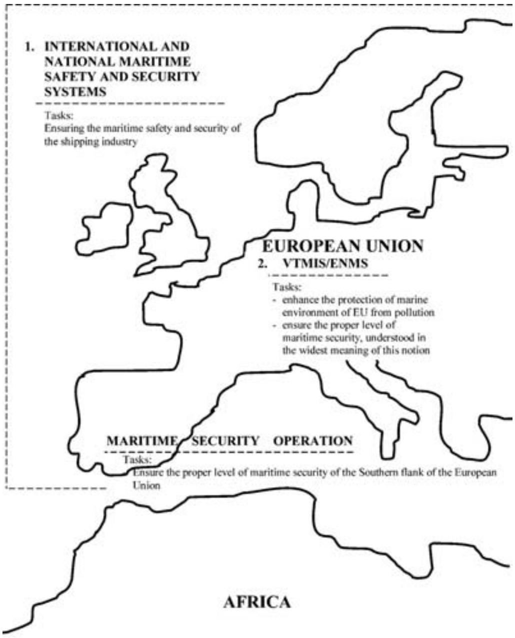

Figure 2. The main means and ways of realization of the compound maritime safety and security function on the maritime areas of the European Union.

function, i.e. the maritime safety and security function of the shipping industry. In Figure 2, there are shown the main means and ways of the realization of the compound maritime safety and security function of shipping industry on the maritime areas of the European Union.

The United States "National Strategy for Homeland Security" (July 2002) [www.whitehouse.gov/homeland/book] in the following way defines the Critical Mission Areas of this function:

- intelligence and warning;
- border and transportation security;
- domestic counterterrorism;
- protecting critical infrastructure and key assets;
- defending against catastrophic threats;
- emergency preparedness and response.

The above critical mission areas of the maritime security function have the general character and therefore they fully regard all Member States of the European Union.

The United States "National Strategy for Maritime Security" (September 2005) [www.dhs.gov/xlibrary/assets/HSDD13_Maritime_Security_Strategy] defines the following threats for this security:

- national-state threats;
- terrorist threats;
- transnational criminal and piracy threats;
- environmental destruction;
- illegal seaborne immigration.

The United States "A Cooperative Strategy for 21st Century Seapower" (October 2007) is the common strategy of all the three maritime military services, i.e. Maritime Corps, Navy and Coast Guard [www.navy.mil/maritime/Maritime_Strategy]. This strategy defines 6 core capabilities. Two of these capabilities, i.e. 5th and 6th can be considered as the core capabilities that concern the maritime security, they are:

- maritime security;
- humanitarian assistance and disaster response.

The maritime security capability is defined as the creation and maintenance of security at sea is essential to mitigate the threats short of war, including piracy, terrorism, weapons proliferation, drug trafficking, and other illicit activities. Counteracting these irregular and transnational threats protects the homeland security, enhances global stability and secures freedom of navigation for the benefits of all nations.

The maritime defence function, as was stated above, is being now closer and closer integrated with the maritime security function, but these two functions penetrate also each other and begin to create one function, i.e. maritime security and defence function.

The subject of the maritime defence function, in relation to the maritime Member States of the European Union and the NATO had been already presented and discussed above. Therefore, we want and will try to discuss shortly the subject of, also already mentioned, the new maritime strategy, i.e. "A Cooperative Strategy for the 21st Century Seapower" [www.navy.mil/maritime/Maritime_Strategy]. It is the strategy of all three maritime military services of the United States.

From the substance and content of this strategy can be concluded that this Strategy is not only the maritime strategy of the United States' Seapower but also the strategy of all the political and military partners of the USA. This Strategy defines, as was mentioned, 6 core capabilities that comprise the essence of the US maritime power and reflects an increase in emphasis on these activities that prevent war and build partnerships. There are defined 6 following capabilities of the US Seapower:

- forward presence;
- deterrence;
- sea control;
- power projection;
- maritime security;
- humanitarian assistance and disaster response.

The last two core capabilities have been already discussed. Therefore below, we will try to discuss the first 4 core capabilities of the US Seapower.

The above first 4 core capabilities are in the reality 4 maritime military strategies, i.e. the navy operational concepts. Two of these strategies existed already in the past (2nd and 3rd). However, two other strategies (1st and 4th) are considerable new. The strategies are forward presence (1st) and power projection (4th) have been formulated and applied by the US Navy and Marine Corps in the last 16 years. Initially these strategies were called as: "... From the Sea" (1992) and "Forward ... from the Sea" (1994).

The "Deterrence" strategy (2nd core capability) was formulated and applied during the cold war. It was especially relevant with regard to the use of nuclear weapons. Now, the concept of "Deterrence" strategy express the truth but mainly the US military policy that "preventing the war is preferable to fighting wars". The "Sea Control" strategy (the 3rd core capability) that very often is also called "Command of the Sea" strategy is one of the oldest maritime strategies. It was formulated and applied already during the age of the sail.

The presented all the 4 core capabilities of the Marine Corps, Navy and Coast Guard, together with 2 other core capabilities discussed before ("maritime security" and "humanitarian assistance and disaster response") constitute the essence of the US "A Cooperative Strategy for 21st Century Seapower".

4 EXPECTED CHANGES IN THE MARITIME SAFETY, SECURITY AND DEFENSE FUNCTIONS

In the above two sections of this paper there have been presented the realization of the maritime safety, security and defense functions in national, regional and international dimension. Also the threats being the subjects of the activities constituting these functions have had mainly the economic, political, military and social character. However, it is evident that in 21st century, besides of the above threats, there are more and more frequently expected other kinds of threats, i.e. natural and other threats that have the global character. Such threats are called the "global calamities". The natural calamities constitute also the component part of the global calamities. There have been commonly agreed that the following calamities are considered as the global calamities [www.unitedcats.worldpress.com/2007/10/11/ten_global_calamities]:

- terrorism;
- climate changes;
- emergent diseases (some contentious forms of incurable virus diseases);
- wars;
- volcanic eruptions;
- asteroid/planet – death from the above;
- methane release (from the continental shelves);
- doomsday devices (nuclear, chemical, biological, etc.);
- strange matter experiments (that can result in global catastrophe);
- aliens (creatures from the outer space).

As the natural calamities are considered the following [http://wiki.answears.com/Q/what_are_the_natural_calamities]:

- earth quakes;
- floods;
- famine;
- volcanic eruptions;
- landslides;
- fires;
- hurricanes;
- tornados;
- ice storms, etc.

The natural calamities are not the new events. They were known since ever. However, the frequency and intensity of these calamities are becoming now higher and higher. That is the result of the climate change. To the global calamities that are manageable, i.e. that might be prevented or whose results might be mitigated, belong the first four global calamities; these are:

- terrorism;
- climate change;
- emergent diseases;
- wars.

Among the global calamities the most dangerous for our planet – Earth and for humans' existence on it, is the climate change. The climate changes, but especially the permanent increase of the temperature, i.e. the global warming, result in the following:

- melting glaciers and land ice (and therefore, in thermal expansion of the water);
- sea level rise;
- changes in the rainfall and evaporation;
- increasing the intensity of natural processes, especially geomorphological processes in the coastal zone, and others.

Preventing the climate change and other global and natural calamities but also economic and social calamities (and mitigating their harmful influence, are tried to be achieved, in global dimension, in the following ways [Sachs, 2005], [Sachs, 2008], [www.un.org/genonto/bp/enviro.html]:

- reduction of the emission of the Greenhouse Gases (GHG), mainly CO2;
- combating the extreme poverty and civilization backwardness;
- protection of the environment (land and maritime) from pollution;
- protecting the biodiversity (land and maritime);
- ensuring the sustainable economic, development, and others.

Taking the above facts into consideration we can draw the following conclusions regarding the expected changes in maritime safety, security and defence functions:

- there exists almost the certainty to assume that such global calamities as terrorism and climate change's effects will be growing permanently and will constitute the main dangers and threats that must be prevented, avoided and mitigated by the maritime safety, security and defence functions;
- the maritime security activities and measures will in higher and higher degree constitute the essence not

only maritime security function but also maritime safety and maritime defence functions;
- the permanently growing dangers and threats, being the effects of the expected natural and global calamities will and must result in the situation that the crisis/calamities response readiness and its efficiency will constitute the main component not only of the maritime security function but also the maritime safety and maritime defense functions.

5 CONCLUSIONS

This paper has been presented the main issues of the functions of maritime safety, security and defense of today and tomorrow. The authors tried to show the main issues constituting the subject and contents of these functions not only today but also in the nearest future. They tried also to show the state of realization of these functions both in the European Union and in the USA. There has been also undertaken the efforts to present the most probably changes' reasons that could influence the realization of these functions and could modify the substance and main tasks of the discussed functions.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

1.2
Study on ships safety control system

X.-J. Han, X.-Y. Meng & Z.-W. Wang
Dalian Maritime University, Dalian, China

ABSTRACT: The proportion of main reasons of ships accidents to the whole reasons is discussed in the paper. Among these reasons, human factors are in the majority. So a method to prevent wrong orders sent by a navigator is laid emphasis on. On the basis of this, a ships safety control system is studied. The construction and control principle of the ships safety control system, as well as control strategy, implementation method and key technology are elaborated in the paper.

1 PREFACE

Although modern ships have been equipped with advanced facilities such as integrated bridge system, automatic navigation device, unmanned engine room, etc, fatal ships accidents still occurred from time to time. Safety has been the key issue which has restricted the development of ships. According to the analysis of ships accidents statistical data from IMO organization, there are three main kinds of reasons which have caused accidents: ① equipment failure in ship itself ② external environment (weather, oceanic condition, etc) ③ human factor.

The proportion of these three reasons to the whole is shown in Fig. 1. From which it is obvious that more than eighty percent of ships accidents are caused by human factor. All the accidents caused by human factor due to wrong operation or misoperation when navigators have poor qualities, lack of watch, have poor capability in dealing with emergency, do not master marine traffic rules enough, etc. Therefore, in order to ensure safety navigating, eliminating the error of human factor is the most important issue we should deal with firstly. Except that the quality of navigator should be improved, ships safety control system should be set up, which would supervise ship's navigating condition, discover potential safety hazard in advance, and estimate the validity of operating order sent by a navigator. Especially in emergency, the system should make estimation rapidly, and then give some appropriate prompt, alarm, or orders of speeding down or blocking operations, so that safety can be ensured and accident can be avoided. The safety control system is studied in this paper. How to forecast ships accident and precaution of wrong order from navigator is the focal issue to be solved.

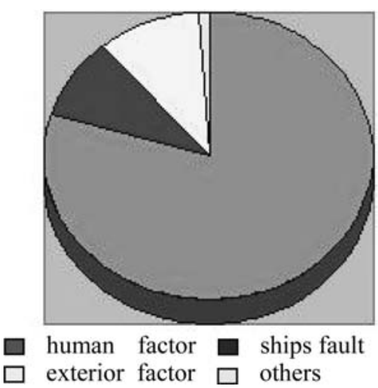

Figure 1. Proportion of reasons in ships accident.

2 BASIC THOUGHT OF SAFETY CONTROL SYSTEM

The ship navigation system is comprised of ship, navigation environment and navigation technology which is shown in Fig. 2.

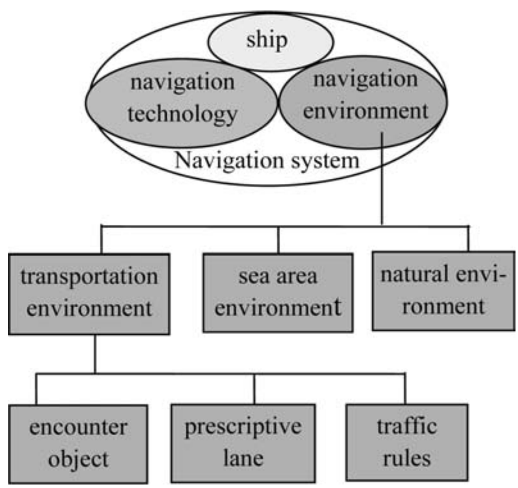

Figure 2. Construction of ship navigation system.

Ship: a moving carrier which includes entity attribute of a ship (weight, size, draught, etc), running condition (course, navigational speed, etc), and motion characteristics (stowage, stability, heel, trim, swinging period, etc.).

Navigation environment: refers to exterior circumstance when ship moves. It contains water area environment, natural environment and transportation environment. Transportation environment covers obstacles in the area of navigation (fixed objects and floating objects), prescriptive lane and traffic rules, such as avoidance regulations, marine transportation safety laws, etc.

Navigation technology is referred to the technology and technique of navigating according to the moving condition of the ship.

It is obvious that among three factors of navigation system, the factor of ship is basically unchangeable, the factor of navigation environment constantly changes. The changes of environment do not lie on human beings. The factor of navigation technology is the drive technology that a navigator adopts based on the former two factors, which includes watching continuous, collecting information, comprehensive analysis, and adjusting according to changes. Thereby, in the course of navigating, navigation technology is the most decisive factor. It has been proved through the facts that most shipwrecks and collision accidents are caused by wrong operation or misoperation.

In recent years, with regard to the constituent of navigation system, great efforts have been made to improve safety of ship navigation. They mainly contain:

1) Improvement of ship: The ship size has been being bigger and bigger. Simultaneity, automation of ship has been being improved greatly. Functions of automatic navigation, supervision and control have been making perfect constantly. And hence ship manoeuvrability has becoming flexible and convenient, such as automatic navigation, location, turning, shifting, emergency shut-down, reversing,etc.
2) Improvement of navigation environment: Navigation environment is involved in transportation environment, sea area environment and natural environment. In which making transportation environment better is easy to be achieved. In recent years, masses of works have been done in scientific setting and management of lane, working out ship collision regulations, improving and perfecting transportation rules on sea, etc.
3) Improvement of navigation technology: For the sake of raising navigators' level of manoeuvre, IMO organization attaches high importance to improving the quality of navigators. They regulated WTC convention (compulsory) strictly for conforming and examining the process of training for navigators, promotion and going on duty, so that navigation technology can be improved.

All the efforts have played a great role in improving ships safety, otherwise, if we want to solve the problem of ships safety radically, a specific ships safety control system should be set up to predict accident potential and access the validity of orders sent by navigator so that human error can be eradicated completely. It is possible because the development of information technology, computer and network technology, as well as expert intelligent control technology, etc.

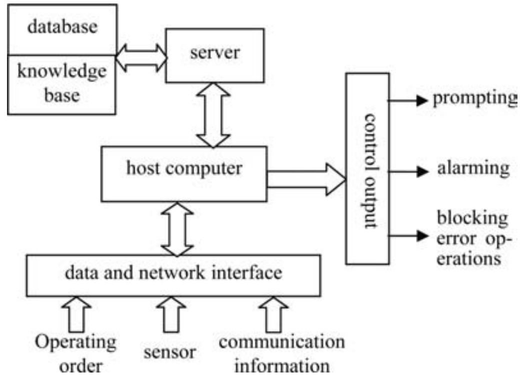

Figure 3. Construction of ships safety control system.

3 CONSTRUCTION OF THE SYSTEM

The core functions of the ships safety control system are forecasting accident potential and evaluating the correctness of each order sent by navigators. On the basis of equipments on board, a safety information network is established which contains a host computer, a server, the interface of data and network, control output, etc. The construction of the system is shown in Fig. 3.

The server is used for information integration, all data involved in ships is stored in it as a database and knowledge base. The interface of data and network is connected to sensors which are used to measure data related to safety ships, such as running parameters of main engine (velocity of a ship, etc.), running parameters of steering engine, information of ARPA, data of GPS, etc. Some data are transferred from sensors to host computer directly, otherwise most information are from network. The host computer is the nucleus of the system. All kinds of running data related to ships are collected then communicated to the host computer, and according to relevant information in the database, running conditions of the ship will be calculated in real time based on a model. Provided a potential risk is predicted, corresponding control will be outputted. The control contains three kinds of outputs: prompting, alarming, and blocking the error operations that could cause severe dangerous effect.

4 SAFE SPEED AND ACCIDENT PRECAUTION

Ship trajectory is determined by the course and velocity of a ship, noted as: $\sum l_i(V_i, S_i)$. Provided that in the area of a ship trajectory at a certain time, encounter objects varies in accordance with V_n^2 or V_p^2. Where, V is the velocity of a ship, n is the number of objects (ships, fixed objects and floating objects), p is the density of objects in the specific area. The encounter rate of the ship with other objects is:

$$\lambda \propto V_n^2 \propto V / V^2 \propto 1/V \tag{1}$$

It is obvious that encounter rate is inverse proportional to velocity of the ship. Although increasing the speed could bring down the encounter rate, but the captain should also keep the ship at a safe speed in the trajectory if he wants to keep the ships safely. The concept of safe speed is put forward in IMO's new rules in 1972. It is defined as the speed relative to water that it can die away completely before the ship arrives at the collision point from anywhere. The concept of safe speed is used as the main foundation in this paper for forecasting ships accident. That is, if actual velocity exceeds the safe speed at any moment in the navigation, accident potential would exist. Based on the scanning information from ARPA radar, the object which is closest to the ship's course is regarded as a reference point at each moment, safe speed could be computed. The period of computing can be set, computing every 1 minute in normal navigation, or computing every 1/2 or 1/4 minute in the area of narrow waters or that the density of navigation object is greater.

There are many kinds of methods to calculate safe speed. In this paper one method is adopted, which is:

$$V_H = \frac{D_r - 2D_s - 2S_r}{2t_p} \tag{2}$$

where, D_r is the distance from the ship to the closest object, D_s is the safe distance which is not more than 1/2 of the distance that the target is in sight, t_p is the time from the target in sight to that an order is sent, S_r is the sliding distance from that an order is sent to that the ship stops completely.

S_r is related to many kinds of factors, such as navigation velocity, braking force, etc. In order to shorten calculating time, a curve of navigation velocity which is corresponding to rev of propeller and braking distance should be stored in the host computer. The curve shows the relationship of ship's true speed V (cable length/min) and rev of propeller according to the result of speed measurement every year on the measurement line, which is shown in Fig. 4. Whenever calculation, firstly, the value of $D_r/2 - D_s$ (cable length/min) is got which is shown as point A in Fig. 4. From the point A, a straight line is drawn parallel to x-axis, which crosses with stop line $(S_P + S_T)$ at the point B (S_T (cable length) is the sliding distance from that the target is in sight to that an order is sent). Then From the point B, a perpendicular line to x-axis is drawn, which crosses with (S_P) at the point C, the rev of propeller can be gotten as a result. Finally, from the point of C, a straight line is drawn parallel to x-axis, which crosses

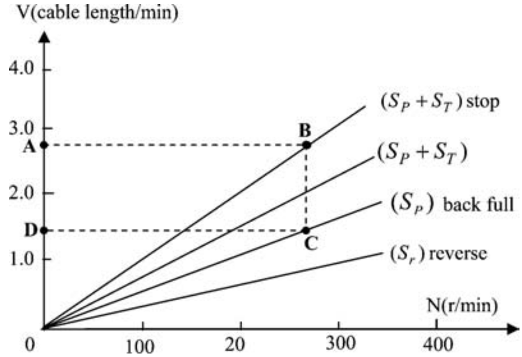

Figure 4. The schematic of computing the safe speed.

with y-axis at point D. The speed in point D is the safe speed.

5 STRATEGIES OF THE SYSTEM

Strategies of safety control system designed in the paper puts stress on calculating safe speed, then predicting accident according to information in database and knowledge base. The strategies can be divided into several types as follows:

(1) When the ship is navigating at sea or on the broad surface of a water area, there are few targets. The safe speed calculated based on the closest distance of objects (very far generally) will be greater than the actual velocity (even greater than the top speed). Risk rate is very small.
(2) When the safe speed calculated is close to the actual velocity, it means that it is near with the closest object. Risk rate is becoming greater. Potential encountering risk exists. At this time, the system should estimate that whether courses of them have the possibility of crossing. If crossing, the system should prompt the navigators.
(3) When the safe speed calculated is less than the actual velocity, it means that the ship is very close to the object, risk rate is much greater. The ship is possible to collide with the object. An alarming signal will be sent immediately and slowing down or stopping the ship according to the difference between the safe speed and the actual velocity.
(4) For each order sent by the navigator (rudder orders and engine orders), the system will search for the new closest object in the new course immediately and calculate the safe speed according to the change of course and velocity after the order is sent. If the safe speed calculated after the order is much less than the speed of the order, it interprets that danger will occur. The system will block the order at once so that it can not be sent to engine room.

For estimating the validity of an order, the system should not only base on the relationship of actual velocity and safe speed after the order is sent, but also

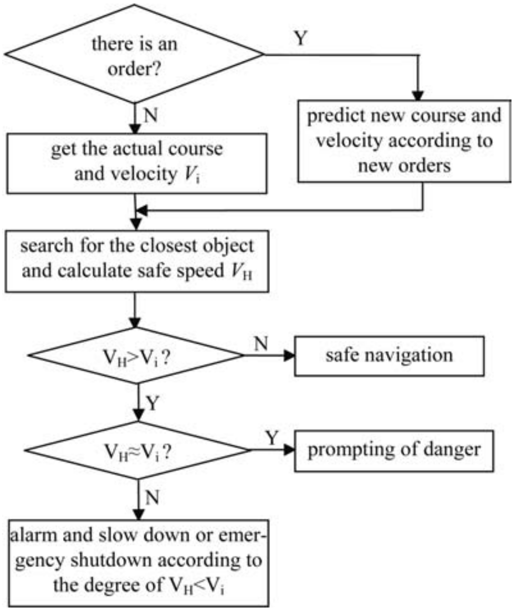

Figure 5. Strategy of safety control.

base on the expert prior knowledge stored in database and knowledge base. Especially for emergency, it is important whether the order conforms to the emergency operation rules and collision avoidance rules. Consequently, it is one of the focal works to build a perfect safety database and knowledge base.

6 CONCLUSIONS

The prediction and safety control of ships accident is made a probe in this paper. The method of predicting an accident according to safe speed and estimating an order in real time is introduced. The key technology is integrating rules of safety relevant information and real-time data processing method. For the reason that there are many complex factors including in the system, many aspects have not been involve in this paper, such as processing rules after information integration, the reliability of sea scanning information, the influence of sea visibility, the real-time requirement of calculating speed, the establishment of expert judgment system, etc. But it is believed that the system of ships safety control system must play a great role in improving navigation safety by our efforts.

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1.3
Marine navigation using expert system

N. Nikitakos & G. Fikaris
University of the Aegean, Chios, Greece

ABSTRACT: A ship's autopilot adjustment is a matter of utmost importance since it affects its safety, command as well as fuel and time efficiency. A number of methods have been developed in order to cope with this issue usually based on models that simulate the weather conditions and adjust the device accordingly. Some of them have a considerable degree of success but none dealt with the problem completely. The main obstacles are the difficulty of simulating the infinite weather and loading conditions and to properly represent them with mathematical equations or rules. This paper describes a method of selecting the best out of a pre-existing set of configurations, taking into account any weather situation, loading condition and type of ship. Moreover, the selected configuration can improve itself during the entire life cycle of the vessel, since it fine tunes its properties for better results. This approach uses Case Based Reasoning as its core technology and is a part of a hybrid system that analyses and solves prefixed problems of maritime interest.

1 INTRODUCTION

An autopilot is defined as a mechanical, electrical or hydraulic system used to guide a vehicle without assistance from a human being. A ship uses an autopilot for steering during her voyages except when she navigates in confined waters or maneuvering at port (COLREGS 72) **[8]**. A ship's voyage may last several days and a large proportion of it takes place in the open sea where the autopilot is used almost exclusively. Even though the ship's bridge, where the autopilot is located, is always supervised by the officer on watch (STCW 95) **[22]**, it is necessary to ensure that the autopilot is a safe and reliable tool in his / her hands.

Keeping a ship on course is not an easy task since ships are exposed to severe weather conditions and are operating in extreme situations. Wind, sea, current, etc, are some of the factors affecting a ship's deviation from the desired course. An autopilot's task is to keep the ship on track, not losing control in any case and simultaneously minimizing the deviations regardless of cause. To do that, an autopilot must have the proper configuration so that it would be able to perform its best according to the situation at hand. This ideal situation is not easy to achieve because the weather combinations of wind, sea, current, etc, are practically infinite and the same stands for the ship's loading conditions which also affect the final outcome. Moreover, an autopilot device is designed to work on almost any type of ship, thus its performance wouldn't be the same in different hulls.

The actual performance of the device is measured using parameters like loss of steering, vertical and angular deviation, extra distance, etc, because they are closely connected to dangerous situations at sea or significant losses of fuel and time. Loss of steering, combined with a generator failure can cause a serious accident i.e. capsize (Leontopoulos 79) **[34]**, while vertical deviation from course (Cross Track Error) leads to unwanted approaches to navigational dangers. Moreover, extreme angular deviations from compass settings affect the ability to command, especially in bad weather (Bowditch 2002) **[6]**. Finally, an incorrect adjustment increases the total voyage distance, the fuel consumption, the time delay and the corresponding costs (Dutton 1958) **[11]**.

Given the above it is very difficult to develop a method that takes into account all the affecting factors and being able to maximize the performance on every ship, under any weather and loading condition. An ideal situation would be the development of a customized device able to "understand" its environment (weather, loading condition and ship's particulars) and properly adjust itself, responding to any changes. Even though such a device is not developed yet, we claim that a pattern able to operate in a similar way is feasible, provided that a conventional device will be equipped with some additional features mentioned below.

This pattern is incorporated as an application within an AI system named POLARIS (**PO**licy **L**eading **AR**tificial **I**ntelligence **S**ystem) (Nikitakos & Fikaris, 2007) **[38]** able to analyze problems of maritime interest and propose courses of action for them. This approach has certain advantages compared to others because it doesn't deal directly with the identification and estimation of the parameter values that constitute a configuration but instead it presupposes an unlimited number of them already installed on the device, with known properties that can be modified according to the user's wishes. There is no limit to the number or nature of the parameters.

The system's core methodology is CBR (Case Based Reasoning) which solves current situations – problems with the assistance of similar cases that were dealt successfully in the past. These cases are stored in a case library and retrieved by the system using the proper indexes. The retrieved cases are ranked according to the criteria and the system proposes the best solution to solve the current problem. If necessary, a solution may be adapted to fit a new situation. When the best solution is proposed a procedure of fine tuning may begin and last till the solution meets the pre specified criteria.

The application described in this paper includes the development of a series of diagnostics performed by the autopilot device in different loading and weather situations in order to measure the corresponding performances and create a case base out of them. Thus, when the ship finds herself in a similar situation, the device will track the case's characteristics, select the case with the configuration that performed best and steer the ship with it until it detects another set of conditions. It is important to mention that the user may choose to measure the performance of a given situation again so that the database would be constantly updated with improved scores.

2 DSS AND CASE BASED REASONING

The literature defines Decision Support Systems (Raiffa 76) **[26]** as "interactive computer based systems that help decision-makers use data and models to solve ill-structured, unstructured or semi-structured problems (Goel 92) **[15]**." The most popular definitions belong to Gorry & Scott-Morton (1971) **[16]**, Keen and Scott-Morton (1978) **[25]** and Bonczek, Holsapple & Whinston (1981) **[5]**. DSS were categorized in seven major categories which are file drawer systems, data analysis systems, analysis information systems, accounting and financial models, representational models, optimization systems and suggestion systems (Alter 1980) **[1]**. A type based categorization defines data driven, model driven (Knowles 89) **[28]** and knowledge driven systems (Dhar & Stein 1997 **[9]**, Holsapple & Whinston 1996) **[20]**).

Knowledge driven DSS -sometimes called Expert Systems- incorporate knowledge about a particular domain, understanding of problem solving and expertise at solving those problems (Redmond 1992) **[42]**. They are also related to data mining techniques and usually evolve to hybrid systems (Simpson, 1985) **[44]**. Major components of a DSS are a) the shell b) the case library c) the knowledge base or the model and d) the system's architecture and network (Sprague and Carlson 1982) **[46]**. These systems analyze data using symbolic logic, have an explicit knowledge base and have the ability to explain conclusions in an understandable way. Web based DSS are referring to a computerized system that delivers decision support information or decision support tools to a manager or business analyst using a "thin client" Web browser (Power 2000) **[41]**.

Reasoning is a procedure that draws conclusions by chaining together generalized rules, usually starting from scratch. However in Case Based Reasoning new solutions are generated not by chaining, but by retrieving the most relevant cases from memory and adapting them to fit new situations (Leake 1996, 2003) **[33][32]**. A case is a contextualized piece of knowledge representing an experience that teaches a lesson fundamental to achieving the goals of the reasoner. A case may have different shapes or sizes, various time horizons and can associate solutions with problems, outcomes with situations or both. A case's main task is to provide a solution to a problem but it can also provide the necessary context to assess or understand a situation (Kolodner 93, Schank 1994) **[29] [45]**. A case is comprised from indexes which should be predictive, goal oriented, abstract and easily recognizable (Birnbaum & Collins 89 **[4]**, Hammond 89 **[18]**). These indexes must describe the problem (goals, constraints and situation), the solution and the outcome. The case base indexing is organized according to the problem's requirements and can be checklist based, difference based (Kolodner 93) **[29]**, similarity and explanation based (Hammond 87, 89 **[17]**), etc. The problem / situation indexes are mainly used for the retrieval, qualification and ranking of cases while the solution indexes present the way of action to the user. The outcome indexes are a part of the evaluation procedure.

The main advantages of CBR are its simplicity, its capability of incorporating uncertainty and its plausibility (Kolodner 1993) **[29]**. Two major classes of CBR systems have been developing since the method's introduction. These are the interpretive and problem solving CBR systems (Rissland, Kolodner & Waltz, 1989) **[43]**. The former use prior cases as reference points for classifying new situations, whilst the latter use prior cases to suggest solutions that apply to new circumstances. Another major advantage of CBR is that because it uses specific episodes (cases) for reasoning there is no need to develop many rules and thus makes the knowledge acquisition process – which is vital to AI systems- very "cheap". As pointed by "Mark et al, (1996)" **[35]** there are some domains that are very suitable for CBR, while others are not, especially if cases are unavailable or in hard to use format. The functions performed by a typical CBR system are recall and interpretation of past experiences (cases), adaptation of those cases to fit the new situation, evaluation of proposed solutions and repair of the "defective" ones (Kolodner, 1993) **[29]**.

POLARIS is an AI system containing elements of a DSS since it interacts with the user and helps him find the best out of a series of alternatives as well as expert knowledge relevant to the problem's domain. The system uses data from old cases to solve new problems but it also incorporates expert knowledge from the problem domain. Thus, its type is a mixture of a data and knowledge driven system strongly dependent on the nature of the application. All these are significantly affected by the complexity of the problem and the domain knowledge available. The system's architecture follows the CBR procedures and comprises of the following modules:

- User interface: interacts with the user
- Case Library: contains the old cases
- Knowledge base: contains the expert knowledge in the form of rules
- Case Retriever: retrieves and ranks the useful cases
- Solution presentation facility: presents the solution to the user
- Solution evaluator: evaluates the solution after the implementation
- Solution adaptor: adapts the solution to fit the current situation
- Case storage facility: stores new cases to the library (Moorman & Ram, 1992) **[37]**

3 ADJUSTMENT METHODS REVIEW

A quick review of the methods used in order to properly adjust a ship's autopilot shows that almost every single AI technology was used by a number of researchers. Fuzzy logic (Polkinghorne M.N; Burns R.S 1994 **[39]**, Roberts G.N, Roberts and Sutton 2006 **[40]**), Neuron Networks (Unar and Murray-Smith 1999 **[48]**, Jia, X.J Yang and X.R Zhao, 2006 **[49]**), Optimization techniques (Holzhuter, 1997) **[21]**, Linear programming (Goheen K.R, Jeffreys E.R, 1990 **[31]**), Model Based Reasoning (Honderd and Winkelman, 1972 **[14]**, Van Amerongen and Udink ten Cate, 1975 **[23]**, Van Amerongen and Van Nauta Lemke, 1986 **[24]**), Self tuning regulators (KJ Astrom et al, 1977 **[27]**), Stochastic models (Ohtsu et al, 1979 **[30]**, Herther et al, 1971 **[19]**), etc, represent only a fragment of the work that has been done in the field.

Most Autopilots are adjusted using the PID controller which calculates a performance variable with known values and applies the necessary corrective actions based on the difference between the calculated and expected value. The controller includes three parts: The first one responds to the error, the second applies a correction for the sum of all the errors and the third responds to the error variation percentage. PID controllers however cannot perform in non linear systems and their accuracy is very low.

Another interesting work is the one of Unar and Murray-Smith who developed an artificial neural network which controls and coordinates a series of conventional controllers. Each controller is manufactured for a specific operational situation of the vessel. Still, the level of detail is low and the situation coverage very poor. Moreover, the system's cost and maintenance is relatively high. This approach has some similarities with CBR since each controller represents a situation, but it is obvious that the number of controllers is finite and cannot cover the infinite weather and loading situations.

4 THE AUTOPILOT APPLICATION THEORY

The Autopilot application presupposes a finite number of configurations available on the device and a number of known parameters which are adjustable and affect the configuration significantly. The system creates a case library performing a series of trials, assessing each configuration's performance for a given situation. The situations and the corresponding performance values are stored in memory and ideally some time during the ship's life cycle there will be a case for almost every combination of weather and loading condition.

When the ship's devices detect a specific weather situation, and given that the loading data as well as the ship's particulars are already stored in memory, the system retrieves the cases with the best performance values from the base. The qualified cases are ranked and the corresponding configuration is presented to the user. After the implementation of the selected configuration the system records the actual performance and compares it with the expected one. If the actual performance is not satisfactory the system either switches to the second best configuration or it enables a fine tuning procedure where it performs a sensitivity analysis of every parameter in the selected configuration aiming to achieve a better performance. If this is accomplished it stores the new set of parameters and the corresponding performance indicators, thus creating a new configuration for the device.

The Autopilot's case contains six categories of indexes which represent the performance criteria (goals), the weather conditions (situation), the loading condition of the ship (situation), the ship's particulars (user characteristics), the configuration used (solution) and the applied performance criteria (outcome).

4.1 *Performance Indexes*

The performance indexes (criteria) mainly cover the dimensions of danger, ease of command, cost and time. Three variables have been used. The first one is the difference of the distance measured by the ship's track to bottom from the rhumb line distance between waypoints (d). The second is the maximum ($dmmax$) and mean vertical deviation to course (XTE) in miles (dm) while the third is the maximum ($ddmax$) and mean deviation of the ship's bow to the true course in degrees (dd). Loss of steering $LS > 0$, $dmmax > threshold1$ and $ddmax > threshold2$ were set as hard constraints. The system is able to automatically calculate all these quantities either separately with the appropriate sensors either using the usual bridge electronic equipment (GPS, ECDIS & ARPA combined) provided that they are connected to the improved Autopilot device.

The first criterion d was selected because it represents the extra distance traveled by the ship in a given part of the journey, so it can be translated to extra

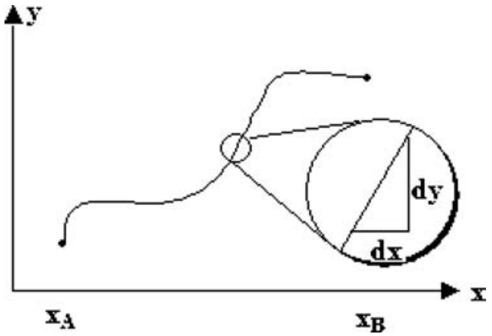

Figure 1. True distance of ship's track to bottom

fuel and time that is monetary cost. The true distance (Figure 1)[1] is calculated using the formula

$$\lambda = \int_{\alpha}^{\beta} \sqrt{1 + \left(\frac{d\psi}{d\chi} \right)^2} \, d\chi$$

The rhumb line distance is k = (ΔΦ)' sec Z whereas Z : true course, so the first criterion equals:

$$d = \int_{\alpha}^{\beta} \sqrt{1 + \left(\frac{d\psi}{d\chi} \right)^2} \, d\chi - (\Delta\phi)' \sec Z$$

Similarly the second criterion's hard constraint is $dm\max = A \tan(\max RB)$ whereas A: ship's advance from extreme vertical XTE point E_i till the next point C_i where it meets the course again and max RB: maximum relative bearing to point E while the mean is calculated as:

$$dm = \sum_1^p A * \tan RB / p$$

where p is the number of selected and calculated XTE points. This criterion expresses the ship's mean XTE from course, thus it's an indicator of possible approaches to navigational dangers like shallow waters, wrecks, etc. The third criterion and the hard constraint that derives from it are:

$$dd = \sum_1^p |Z\max - Z| / p \text{ and } dd\max = |Z\max - Z$$

These express the selection's performance in steering or the ship's "swinging" on either side (Leontopoulos 1979) **[34]**. Those criteria were combined to measure the negative performance of each alternative. The analysis[2] assigned 5 negative points for each extra mile, 10 points for each XTE mile and 0, 2 for each degree of deviation. Moreover, the two hard constraint thresholds were set to 0.02 miles / Beaufort for *dmmax* and 2 degrees / Beaufort for *ddmax*.

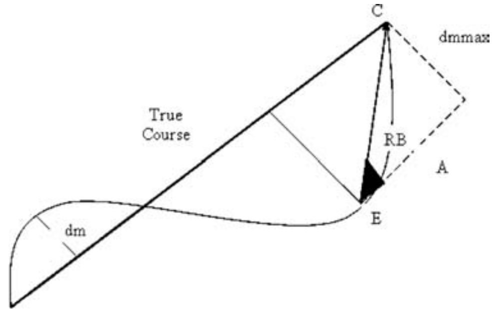

Figure 2. Vertical deviation – Max and mean

Dmmax is increased by 20% for each knot of current with a relative bearing > 45°. These are default values and are justified after a survey with experts aiming to assess the severity of each criterion as far as the autopilot device is concerned. If the user disagrees he / she can intervene and change this balance by inserting values to the coefficients α, β, γ assigned to each criterion during the interaction with the system. After the normalization the selection's negative performance is calculated as follows:

$$NP = a\left[\left(\int_{k}^{lb} \sqrt{1 + \left(\frac{d\psi}{d\chi} \right)^2} \, d\chi\right) - (\Delta\phi)' \sec Z\right] +$$
$$+ \beta\left(\sum_1^p A * \tan RB\right) / p + \gamma\left(\sum_1^p |Z\max - Z|\right) / p$$

4.2 *Wheather condition indexes*

The weather condition indexes describe the wind, sea and current. The case includes wind direction and force, sea direction and force, current direction and speed as well as swell direction and height. All directions are expressed in degrees, wind and sea force in Beauforts, current speed in knots and swell height in meters. All directions are relative to bow and current speed is true. A situation is considered identical when the parameter differences will not exceed half of a preset allowance in either direction (+/−). As the case library grows bigger the boundaries can be stricter for better accuracy.

The weather situation is expressed by four major phenomena which are wind, sea, current and swell. Sea condition will always be a part of the situation during the retrieval procedure, while current, swell and wind can be omitted if there are not any exact matches. If the phenomenon is to be included in the case retrieval process, its indexes are analyzed further in order to determine their actual importance and whether they should be included as retrieval criteria. Table 1 shows a strict version of the retrieval process because the criterion used is the existence of a Medium importance (M) characterization for the relative course or the sea force. Relative course has three importance levels (Low, Medium, and High) covering 30 degrees

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[1] Axis x refers to geographical longitude and axis Y to latitude

[2] The thresholds are for a 65000 DWT Panamax bulk carrier. For other types of ships the numbers are different, slightly increasing with the tonnage

Table 1. Combined importance of sea direction and force (Medium and High Importance Thresholds are set).

	1 – 2	3 – 4	5 – 6	7 – 8	9 – 10	11 – 12
0 - 30	L-VL	L-L	L-M	L-H	L-VH	L-EH
31 – 60	M-VL	M-L	M-M	M-H	M-VH	M-EH
61 – 90	H-VL	H-L	H-M	H-H	H-VH	H-EH
91 – 120	H-VL	H-L	H-M	H-H	H-VH	H-EH
121 – 150	M-VL	M-L	M-M	M-H	M-VH	M-EH
151 – 180	L-VL	L-L	L-M	L-H	L-VH	L-EH
181 – 210	L-VL	L-L	L-M	L-H	L-VH	L-EH
211 – 240	M-VL	M-L	M-M	M-H	M-VH	M-EH
241 – 270	H-VL	H-L	H-M	H-H	H-VH	H-EH
271 – 300	H-VL	H-L	H-M	H-H	H-VH	H-EH
301 – 330	M-VL	M-L	M-M	M-H	M-VH	M-EH
331 - 360	L-VL	L-L	L-M	L-H	L-VH	L-EH

	1 – 2	3 – 4	5 – 6	7 – 8	9 – 10	11 – 12
0 - 30	L-VL	L-L	L-M	L-H	L-VH	L-EH
31 – 60	M-VL	M-L	M-M	M-H	M-VH	M-EH
61 – 90	H-VL	H-L	H-M	H-H	H-VH	H-EH
91 – 120	H-VL	H-L	H-M	H-H	H-VH	H-EH
121 – 150	M-VL	M-L	M-M	M-H	M-VH	M-EH
151 – 180	L-VL	L-L	L-M	L-H	L-VH	L-EH
181 – 210	L-VL	L-L	L-M	L-H	L-VH	L-EH
211 – 240	M-VL	M-L	M-M	M-H	M-VH	M-EH
241 – 270	H-VL	H-L	H-M	H-H	H-VH	H-EH
271 – 300	H-VL	H-L	H-M	H-H	H-VH	H-EH
301 – 330	M-VL	M-L	M-M	M-H	M-VH	M-EH
331 - 360	L-VL	L-L	L-M	L-H	L-VH	L-EH

from bow and sea force has six levels (Very Low, Low, Medium, High, Very High, and Extremely High) each covering two Beauforts. As seen in table 1, in almost all cases the sea indexes should be included in the retrieval. The lower part presents the same data but now the criterion is the existence of a High importance (H) in any of the two indexes.

The influence of the sea condition parameter is affected by a lot of things, but since the case refers to the same ship, the only other factor to be considered is the loading situation. Sea direction and force has a much greater impact when the ship is on ballast and less when it's fully loaded. Thus, when the vessel is on ballast condition more weather combinations should be included. The strict version is used for ballast condition and the less strict for the fully loaded condition. Further division i.e. semi loaded condition can be applied if needed.

Current, swell and wind are represented similarly in the knowledge base. Importance weights were assigned to each direction for each one of the three phenomena. Current was given a scale of 0–10 knots ranging from Very low to Very High importance with a pace of 2 knots. The existence of a Medium importance is the criterion when the ship is on ballast condition while a value of High importance is necessary when the ship is loaded. Swell is measured with a scale of 0–5 meters ranging from Very Low to Very high importance while wind has the same scale as the sea. The thresholds are at least one Medium importance for the ballast and at least one High importance for the fully loaded condition.

4.3 *Loading condition and ship particulars indexes*

The loading condition indexes include information about the deadweight, draft, trim, declination, LCG, VCG, TCG, free surfaces, hogging and sagging. Additional indexes include the capacity used, type of cargo, fuel, ballast, supplies or alternative ones like hull coefficient proportions, stowage factors, etc. The ship's particulars represent the user characteristics and include the basic dimensions, ship's coefficients, RPM (sea speed), rudder elements, maneuvering characteristics, etc. The loading condition and the ship particulars indexes are presented in table 2.

The loading indexes are identified after interviews with merchant ship masters and deck officers with more than adequate experience in the field. Importance weights have been assigned to each one of them in order to identify those necessary to be included as criteria in each retrieval procedure. The indexes with the highest importance are the DW, d, δ, dec, VCG, Io, SF and the Ballast percentage. All others are already covered by them and exist for accuracy reasons. It should be noted that any of these indexes can be omitted if the user wishes to or if the case library is not rich enough and cannot retrieve exact matches. Also, the value boundaries can change to permit a stricter or a more loose retrieval in accordance with the needs.

The ship's particulars indexes describe the user (ship) characteristics. Even though the Autopilot application refers to the same ship the particulars are inserted in the library in case a possible user company decides to integrate the fleet's libraries to create a richer one, especially if there are vessels with similar characteristics. Like every category of indexes and as the case library grows more indexes can be added or stricter criteria can be set.

4.4 *Solution and outcome indexes*

In this application the solution parameters are only the configuration with the best performance and its corresponding characteristics. For simplicity reasons we included two attributes (for demonstration purposes only) which are the angular velocity of the rudder (AVR) and the rudder angle permitted (RA) in order to keep the ship on course. The configurations available can be any combination of these values, thus for AVR values $n-2$, n and $n+2$ degrees per second and RA values of $k-5$, k and $k+5$ degrees we have 9 possible combinations, plus a ($n-4$, $k-10$) combination for very calm sea. Finally, the outcome indexes are the same as the criteria indexes, but their values will be the actual performance of the configuration during the voyage.

4.5 *Case retrieval*

Case retrieval is one of the most important parts of the system's reasoning since it is required to select all the related cases, classify them according to their utility towards the goals and promoting the most promising of them. As mentioned in the literature the proper retrieval requires a degree of similarity between the new and the retrieved situation. Many CBR systems use various levels of abstractions in order to recognise similarities between cases of different domains. There

Table 2. Loading condition and ship particulars indexes.

Index	Description	Importance	Index	Description	Importance
C%	Cargo percentage	High	Hog	Hogging	Low
d	Draft	High	Sag	Sagging	Low
δ	Trim	High	SF	Stowage Factor	High
dec	Declination	Medium	U	Ullages	Medium
LCG	Longitudiotal C.G.	Medium	F%	Fuel percentage	Low
VCG	Vertical C.G.	High	B%	Ballast percentage	High
TCG	Transverse C.G	Medium	S%	Supplies percentage	Low
Io	Free Surfaces	Medium			
LOA	Length overall	High	RPM	Revolution per min	High
MaxB	Max breadth	High	Pitch	Propeller pitch	Low
Hgt	Height	Low	Prop	Propeller turn	Low
Cx	Hull coefficient	High	Rud	Rudder surface	High
Ca	Frame coefficient	Medium	Bulb	Bulbous buoy	Medium
Cw	Water plate coeff	High	Stern	Stern type	High
Cp	Prismatic coeff	High			

are numerous algorithms used for the case retrieval strongly dependent on the problem complexity. Usual serial algorithms are the Flat memory – serial search enhanced with shallow indexing, case library partitioning or synchronous parallel retrieval (Kolodner 93) **[29]**, Shared Featured Networks (Fischer 87 **[13]**, Michalski and Stepp 83 **[36]**, Cheeseman 88 **[7]**, Quinlan 86), Discrimination Networks (Feigenbaum 63) **[12]**) and Redundant Discrimination Networks (Kolodner 93) while parallel algorithms are Flat Library – Parallel search (Stanfild and Waltz 81, 88 **[47]**, Simoudis 91, 92, Domeshek 89, 91 **[10]**), Hierarchical memory – Parallel search (Kolodner 93) **[29]**. A serial search is used for the Autopilot application assisted by a case library partitioning using the sea condition indexes. Other situation parameters can be used in case the library grows very big.

When the system detects the cases whose values fall into the ranges permitted it uses the nearest neighbour approach (Dasarathy 1991) **[3]** for each selected characteristic in order to assess the degree of situation similarity. This leads to the retrieval of a set of cases which are ranked according to the criteria. In the Autopilot's knowledge base the priorities are safety, command and monetary cost, so the goals are ordered with this logic: Loss of steering, vertical deviation, angular deviation and finally difference of distance. The system rejects any case that violates a hard constraint and then calculates the negative performance of the remaining cases, proposing the one with the lowest score to the user.

4.6 *Evaluation and adaptation*

The evaluation procedure is the comparison of the actual performance of the configuration used with the one stored (the best) in the case library. If the performance is not satisfactory the user has two choices. One is to select the second best configuration for the specific situation and store it in memory and the second is to adapt the selected configuration to fit the new situation. This is done by initiating a fine tuning procedure (or sensitivity analysis) where the system changes the configuration parameter values and performs a new series of diagnostics in order to track the adapted configuration with the best performance. In the Autopilot application the system assesses the performance of the adapted configurations relatively easy since the parameters are only two (AVR & RA) and the possible combinations no more than ten. Of course the configuration parameters can be much more, with the system's processing time increasing exponentially but then, fuzzy logic classifications can be used to reduce the processing time. One way to avoid that is to categorize the configurations in classes and further examine them if the performance is not adequate.

There is no adaptation procedure in this particular applcation because the suggestion's outcome is an already preset configuration with fixed attributes. Moreover, instead of trying to modify the reasoning or re configurate the solution, it is far more preferable to simply use the second or third best configuration proposed by the system or re run the diagnostics with less strict constraints.

5 CASE STUDY

A 65000 DWT bulk carrier was selected for this case study which is presented based on real voyage data except the values of the performance criteria, since such a device is not developed yet. The ship sailed from Los Angeles (USA) to San Bernardino (Philippines) and performed its diagnostics during a great circle trip. The ship is loaded with corn and travels at usual sea speed. We suppose there is an autopilot on board that has 10 different selections, so the diagnostic test will be performed 10 times in each part of the

Table 3. Initial voyage data.

Initial data	Way Point Data			
	DepLat	DepLong	ArrLat	ArrLong
Departure Lat: 34° 00′ N	34 00 N	120 40 W	37 16 N	130 00 W
Departure Long: 120° 40′ W	37 16 N	130 00 W	39 31 N	140 00 W
Arrival Lat: 12° 45′ N	39 31 N	140 00 W	40 51 N	150 00 W
Arrival Long: 124° 20′ E	40 51 N	150 00 W	41 19 N	160 32,7 W
Great circle dist: 6156,6 m	41 19 N	160 32,7 W	40 51 N	170 00 W
Rhumb line dist: 6446,6 m	40 51 N	170 00 W	39 31 N	180 00
Great circle diff: 290 m	39 31 N	180 00	37 16 N	170 00 E
Initial course: 295°	37 16 N	170 00 E	33 56 N	160 00 E
Vertex Lat: 41° 19′ N	33 56 N	160 00 E	29 25 N	150 00 E
Vertex Long: 160° 32,7′ W	29 25 N	150 00 E	23 42 N	140 00 E
Vertex dist: 1927 m	23 42 N	140 00 E	16 42 N	130 00 E
	16 42 N	130 00 E	12 45 N	124 20 E

Table 4. The weather conditions during the diagnostic test.

Diagnostic Selection	Wind Rel. Dir.	Wind Force	Sea Rel Dir	Sea Force	Current Rel Dir	Current Speed	Swell
1.1	−35	6	85	5	85	1,5	No
1.2	−40	7	90	6	90	2	No
1.3	−30	7	90	6	90	2	No
1.4	−35	7	90	7	90	2	No
1.5	−45	6	100	6	95	1,5	No
1.6	−35	6	100	5	95	1,5	No
1.7	−20	7	100	6	95	2	No
1.8	−35	6	100	5	95	2	No
1.9	−25	6	100	6	95	2	No
1.10	−35	6	105	6	100	2	No

great circle given that every part has significantly different weather conditions. If this ideal situation occurs a case base of $10 \times 11 = 110$ cases will be constructed in a single trip. The great circle data are shown in table 3. It must be noted that the rest of the case study is focused to the first way point for simplicity reasons, since the procedure is similar for every other part of the voyage. The distance set for each selection is 10 miles, thus the first test will cover a total distance of 100 miles.

A general description of the voyage is as follows: The ship's draught was 13.3 meters, the cargo holds were full and the stowage factor was 1.52. There was no hogging or sagging and the trim was 1 meter by the stern. The engine's RPM were 110 and the ship's initial stability satisfactory since the GM was 25 centimeters. The ship's heading was 295 during the first diagnostic and the wind was NW 6-7. The sea was NNE moderate to rough and the current 2 knots to the starboard beam.

The situation was presented with two sets of variables –weather and loading parameters- and a third set which is already inserted in memory representing the ship's particulars. The variables used for the weather conditions are the relative directions of sea, current, wind and swell and are listed in table 4. The weather situation is identical since the heading and distance traveled for each test is the same (295, 10), the wind[3], sea and current differences do not exceed the allowances permitted and there is not any swell. The loading situation was represented using the cargo (+/−25*TPC[4] % MT), draft (+/−0, 25 m), SF (+/−0, 05), % hold capacity (+/−10%), RPM (+/−2%), VCG (+/− 0, 05 m) and trim (+/−0, 5 m) variables. The parentheses show the allowances for the loading situation similarity. The loading situation is shown in table 5. Table 6 shows the case as it is stored in the case library.

Table 7 presents a scenario of possible criteria values measured during the diagnostics. These include the criteria measuring the performance as well as the hard constraints with their respective thresholds. The

[3] The (-) declares left (port) from bow

[4] Tons Per Centimeter: the amount of cargo required to alter the ship's draft for 1 centimeter

first hard constraint eliminates three selections since the maximum vertical distance dmmax exceeds the threshold dmmaxTh. Thus, selections 1.1, 1.2 and 1.3 are no longer considered. Similarly the second constraint ddmax eliminates the selections 1.6 and 1.10 since the value must be below the limit and not equal. The third constraint which requires zero tolerance to steering losses eliminates selections 1.6 and 1.7 as well as 1.2 and 1.3 which were already excluded. At this point selections 1.4, 1.5, 1.8 and 1.9 remained active and the system calculates their negative performance NP in order to rank them. Finally, selection 1.8 is proposed as the best alternative since it has less negative points than the others.

An estimation of the potential benefits resulting from a proper selection is shown comparing the better with the worst alternative not taking into account the hard constraints that exclude it. Those alternatives are 1.8 and 1.2. Criterion d shows that the ship travels

Table 5. The loading condition during the diagnostic test.

Index	Description	Index	Importance
C%	100%	Hog	Not used
d	13,3	Sag	Not used
δ	−1	SF	1,52
dec	0	U	Not used
LCG	Not used	F%	Not used
VCG	0,25	B%	0%
TCG	Not used	S%	Not used
Io	Not used		

Table 6. The situation as it is stored in the base.

Diagnostic Selection	Wind Rel. Dir.	Wind Force	Sea Rel Dir	Sea Force	Current Rel Dir	Current Speed	Swell	Displ
1.1	−35	6	85	5	85	1,5	No	No
1.2	−40	7	90	6	90	2	No	No
1.3	−30	7	90	6	90	2	No	No
1.4	−35	7	90	7	90	2	No	No
1.5	−45	6	100	6	95	1,5	No	No
1.6	−35	6	100	5	95	1,5	No	No
1.7	−20	7	100	6	95	2	No	No
1.8	−35	6	100	5	95	2	No	No
1.9	−25	6	100	6	95	2	No	No
1.10	−35	6	105	6	100	2	No	No

Selection	Displ	Hull C	Draft	SF	Capac.	GM	Cargo	RPM	Io	Trim	Hog	Sag
1.1	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0
1.2	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0
1.3	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0
1.4	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0
1.5	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0
1.6	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0
1.7	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0
1.8	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0
1.9	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0
1.10	No	No	13,3	1,52	100	25	Grain	110	0	−1	0	0

Table 7. Criteria and hard constraints.

Selection	d	dm	dmmax	dmmaxTh	dd	ddmax	ddmaxTh	SL	NP
1.1	0,8	0,1	0,12	0,1	9	11	12	0	6,8
1.2	1,2	0,15	0,18	0,12	13	**15**	12	**1**	10,1
1.3	0,9	0,12	0,13	0,12	11	**13**	12	**1**	7,9
1.4	0,5	0,05	0,07	0,14	10	12	14	0	**5**
1.5	0,3	0,02	0,04	0,12	5	7	12	0	**2,7**
1.6	0,6	0,055	0,07	0,1	8	**10**	10	**1**	5,15
1.7	0,7	0,06	0,08	0,12	9	11	12	**1**	5,9
1.8	0,3	0,02	0,03	0,1	4	6	10	0	2,5
1.9	0,3	0,025	0,04	0,12	5	6	12	0	**2,75**
1.10	0,8	0,11	0,12	0,12	13	**15**	12	0	7,7

0, 9 extra miles[5] in every 10 miles of journey. This means that during this passage the ship will travel 6156, 6 * 0, 9/10 = 554 extra nautical miles and will lose 554/15 = 37 hours in terms of time. Moreover the ship will vertically deviate (mean) from its course 278 meters more and swing about 10 degrees more (mean) if 1.2 is selected. This means bigger exposure to danger and greater difficulty in command which in turn wears the hull, engine, propeller, etc. One must not forget the additional wear and tear of the rudder and engine if a false steering configuration is set as well as the crew fatigue and other damages that may result from rolling, pitching, etc.

6 CONCLUSION – FUTURE RESEARCH

Summarizing the above it is concluded that a way of selecting the best alternative from a pre existing set of configurations of an autopilot is possible using CBR as the core technology. Since such a device is not yet developed this application is considered conceptional and its main task was to present some initial thoughts still requiring verification and hard data. The development of a prototype could give a lot of answers and test the system's performance in the real world.

Apart from that we strongly believe that the maritime industry and especially the ship is a very compatible environment for CBR and numerous applications could be developed. In time, an integrated system able to deal with a number of issues could be developed and with the accumulation of cases its performance and learning will constantly improve.

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[5] Additional miles travelled if instead of the best, the worst performing configuration is selected by the device

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1.4
Safety of navigation and spatial planning at sea

J. Hajduk
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: Until recently the concept of spatial planning concerned only land areas, chaos prevailing at sea in this scope. Vessel routes were selected by the Master on the principle of “freedom of navigation”. It was similar with the submarine routes of pipelines and cables, wind farm construction zones, excavation of aggregates, or the conduct of any human activity at sea.

A systemic approach is introduced and preferred currently, which is to take into consideration the natural conditions and human achievements on one hand, and look ahead on the other, systematising procedural activities and minimising possible conflicts of interests among potential users of the sea.

1 INTRODUCTION

Marine navigation has been practised by man for ages. In particular phases of civilisation’s development more and more new forms of human activity at sea have appeared. Fishery, the conduct of submarine cables and pipelines, excavation of natural resources from under the sea bottom, last but not least the construction of artificial islands and wind farms are only the chief activities conducted currently by man at sea.

The undertaking of new initiatives at sea by man and increasing their scope makes it necessary to order them in long-term perspective lest their mutual interaction should cause conflicts. This pertains both to marine shipping and to other forms of man’s economic activity on a micro-scale understood as a coastal state and on a macro scale understood as influence on neighbouring states and transit shipping. The priority is safety and marine environment protection.

Recently, as part of working out a marine policy, the European Union has, among other things, laid stress on spatial planning at sea. According to Blue Book (EU 2007), increasing competition for marine space and the cumulative impact of human activities on marine ecosystems render the current fragmented decision-making in maritime affairs inadequate, and demand a more collaborative and integrated approach. For too long policies on, for instance, maritime transport, fisheries, energy, surveillance and policing of the seas, tourism, the marine environment, and marine research have developed on separate tracks, at times leading to inefficiencies, incoherencies and conflicts of use.

Based on this recognition, the Commission’s vision is for an integrated maritime policy that covers all aspects of our relationship with the oceans and seas. This innovative and holistic approach will provide a coherent policy framework that will allow for the optimal development of all sea-related activities in a sustainable manner”.

An integrated governance framework for maritime affairs requires horizontal planning tools that cut across sea-related sectoral policies and support joined up policy making. The following three are of major importance: maritime surveillance which is critical for the safe and secure use of marine space; maritime spatial planning which is a key planning tool for sustainable decision-making; and a comprehensive and accessible source of data and information.

According to the Blue Book (EU 2007) a Roadmap for Maritime Spatial Planning: Achieving Common Principles in the EU has recently been accepted (EU 2008). According to the records of this plan: Maritime Spatial Planning is a key instrument for the Integrated Maritime Policy for the EU. It helps public authorities and stakeholders to coordinate their action and optimises the use of marine space to benefit economic development and the marine environment. This Communication aims to facilitate the development of Maritime Spatial Planning by Member States and encourage its implementation at national and EU level. It sets out key principles for Maritime Spatial Planning and seeks, by way of debate, to encourage the development of a common approach among Member States.

Particular European countries have so far reached different degrees of progress in the scope of spatial planning at sea. New organisational solutions are implemented and the related documents are temporarily of “proposition” status and are passing through the stage of domestic and international agreements (EU 2008).

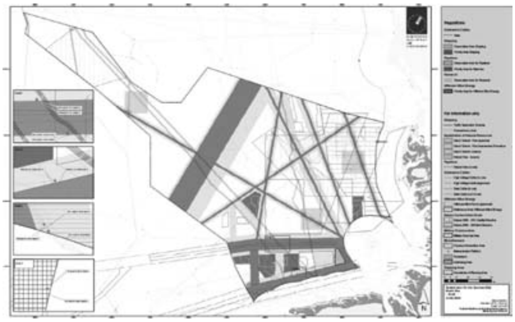

Figure 1. Spatial Plan for the German Exclusive Economic Zone (Draft) – Regulations- North Sea (http://www.bsh.de/en/The_BSH/Notifications/Draft_map_North_Sea.pdf).

Figure 2. Spatial Plan for the German Exclusive Economic Zone (Draft) – Regulations- Baltic Sea. (http://www.bsh.de/en/The_BSH/Notifications/Draft_map_baltic_sea.pdf).

2 DRAFT SPATIAL PLANNING IN THE GERMAN EXCLUSIVE ECONOMIC ZONE (EEZ)

The proposal put forward by Germany in June 2008 (BSH 2008) takes account of the following forms of human activity at sea:

- shipping,
- exploitation of non-living resources,
- pipelines and submarine cables,
- marine scientific research,
- energy production, wind energy in particular,
- fisheries and mariculture,
- protection of the marine environment

For shipping, on the other hand, the following chief objectives and principles have been set down (BSH 2008):

1. Shipping is granted priority over the other spatially significant uses in the priority areas for shipping as indicated in the map (Figures 1&2). To the extent spatially significant planning, measures and projects are not compatible with the function of the shipping priority area in these areas they are not permitted.
2. Special consideration is given to shipping in the reservation areas for shipping as indicated in the map. This needs to be taken into account in a comparative evaluation with other spatially significant planning tasks, measures and projects.
3. Pollution of the marine environment by shipping shall be reduced.

Besides applicable regulations of IMO, the "best environmental practice" according to the OSPAR (The Convention for the Protection of the Marine Environment of the North-East Atlantic) and HELCOM (The Convention on the Protection of the Marine Environment of the Baltic Sea Area) Conventions and the respective state-of-the-art technology shall be taken into account.

Generally, the objectives pertaining to shipping have been set down correctly in the proposal. In Figure 1 the presented main and reserve shipping routes in the North Sea do not arouse controversies. The planned main shipping routes and reserve shipping areas overlap with the main routes of vessel traffic flow and take account of the increased number and size of ships, including difficult hydrometeorologic conditions and emergency situations.

The problem of EEZ zone in the Baltic Sea has been tackled in a completely different way, on the other hand (Fig. 2). Only the vessel traffic from the Kiel Canal and the Great Belt to the north-east in the direction of the Bornholmsgat has been considered. No vessel traffic to and from the ports of Swinoujscie and Szczecin has been taken account of, which may pose a threat to navigational safety in future and cause sea accidents. At present there are two shipping routes leading up to the ports of Swinouj-scie/Szczecin. The first and basic one is located eastward off the coasts of Rügen on Germany's territorial waters.

The other, an alternative one, runs outside of Germany's territorial waters. There is also a shipping route linking by the shortest distance the ports of Swinoujscie and Ystad in Sweden.

What is more, when planning the future no account has been taken of the shipping route southwards of Bornholm Island, an outline of which was presented in the form of a traffic separation schemas (TSS) in a common Polish-German document at a meeting of IMO NAV Subcommittee (Fig. 3).

The shipping route planned is of high importance for vessels in transit towards the ports of the Gulf of Gdansk and ports in the Kaliningrad District, in Lithuania, Latvia and Estonia. The key location limiting the vessel traffic to the south of Bornholm Island is designation of the vessel traffic separation zone between the Adlergrund and Odrzana Bank. The wreck of Jan Heweliusz ferry is an additional obstacle to navigation in the rather narrow deep-water strip.

Another problem in the proposed plan of spatial development is the marking of the northern approach fairway and anchorages of Swinoujscie port as politically disputable area. According to the Polish party's knowledge the problem was solved by a bilateral agreement with the German Democratic Republic

Figure 3. Planned Routeing Measures for the Southern Baltic (IMO 2008).

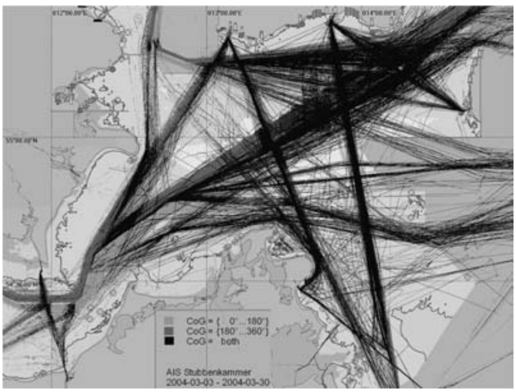

Figure 4. Traffic on the west part of the Baltic Sea (example).

in 1989 and confirmed by the Federal Republic of Germany (Dz.U. 1989).

3 VESSEL TRAFFIC IN THE GERMAN EEZ IN THE BALTIC

As presented in Figure 4, vessel traffic in the western part of the Baltic runs in many directions. The basic flow of vessel traffic falls into line NE-SW on the route from Gedser towards Bornholmgast. Additional routes run to/from the port of Swinoujscie by two ways, one along the island of Rügen and another by vessels plying to Ystad. Vessel traffic can also be observed below the island of Bornholm on an inter-shoal inlet, where a vessels TSS is planned (Fig. 3). Traffic of vessels with smaller draft also runs to the north of the planned TSS.

When planning vessel traffic the prevailing trends and planned investments should be taken into account. Among the latter in the region there is the LNG terminal, to be started about 2012 in the external port of Swinoujscie.

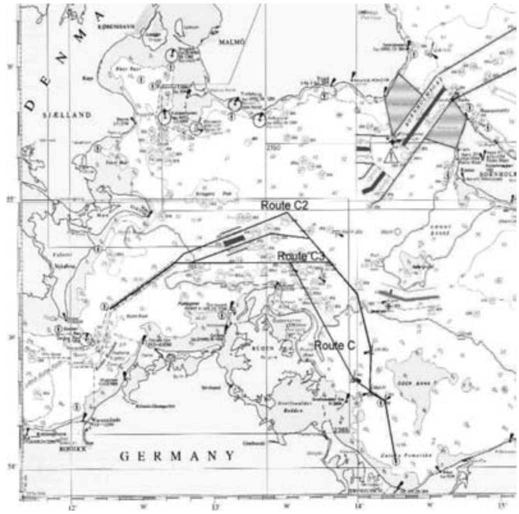

Figure 5. Routes to Swinoujscie from/to West (Hajduk J. & Montewka J. 2007).

The traffic of gas carriers with draft of the order of 12.5 m and about 300 m length is planned alternatively on two basic routes (Fig. 5):

- basic route C skirting the coast of Rügen Island,
- alternative route running along the northern approach fairway outside of Germany’s territorial sea waters, indicated in the north as alternative, with inclusion in the traffic of North Rügen separation zone or at Arkona buoy.

The existing vessel traffic and traffic generated by the planned investment in the form of LNG terminal should be taken into account in the spatial planning of this water area; otherwise, a menacing situation may needlessly be created in future caused by using traditional and basic shipping routes for other forms of human activity at sea.

4 REMARKS FOR THE PRESENTED PROPOSAL OF SPATIAL PLANNING OF THE GERMAN EEZ

Figure 6 presents a suggestion for correcting the spatial planning of the German EEZ, out of concern for navigational safety in future. The remarks amount to the following (Fig. 6):

- taking account of and plotting of shipping routes planned as alternative for LNG gas carriers calling in future at the Swinoujscie terminal,
- plotting shipping routes traditionally used by sea ferries plying between Swinoujscie – Ystad,
- taking account of the shipping route southwards of Bornholm Island with consideration to the planned vessels TSS,

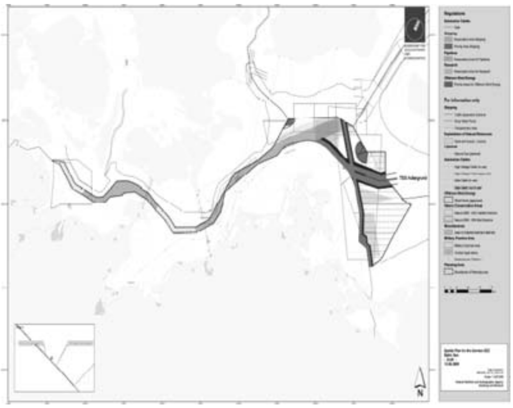

Figure 6. Proposal for correction of the Spatial Plan for the German Exclusive Economic Zone (Draft) – Regulations-Baltic Sea.

– independently of the political status, which should be solved on another plane, the approach fairways and anchorages of Swinoujscie port must be marked as areas reserved for shipping.

5 SPATIAL PLANNING IN POLISH SEA AREAS

At present, spatial planning of sea areas is provided for in Polish legislature (Dz. U. 2003 a, b).

Currently, in accordance with delegation of art. 37b par. 4 of Act of 21st March 1991 r. on sea areas of the Polish Republic and maritime administration, quote "the minister proper for construction, spatial and housing economy shall determine by way of ordinance the required planning scope of spatial development of interior sea waters, territorial sea and exclusive economic zone in the textual and graphic parts, taking particular consideration of requirements pertaining to planning materials, kind of cartographic studies, applied markings, terminology, standards and way of documenting planning work".

The above-mentioned authorisation was put into effect on 11th July 2003 in connection with the Act of 27th March 2003 on spatial planning and development (Dz. U. 2003 a), which was introduced into the Act on sea areas of the Polish Republic and maritime administration in part II, chapter 9, granting the minister proper for construction, spatial and housing economy competences to accept plans of spatial development of interior sea waters, territorial sea and exclusive economic zone. (According to art. 37a par. 1 and art. 37b par. 1 of Act of 21st March 1991 r. on sea areas of the Polish Republic and maritime administration, quote "Art.37a par.1.-The minister proper for matters of construction, spatial and housing economy in cooperation with the ministers proper for matters of sea economy, agriculture, the environment, internal affairs and national defence may accept and order a plan of spatial development of sea internal waters, territorial sea and exclusive economic zone, taking consideration of establishments determined in Pass. 2 and issued valid permissions mentioned in Art. 23 and Art. 23a. – Art. 37b. par.1. – The draft of a plan for spatial development of sea internal waters, territorial sea and exclusive economic zone is prepared by the director of the maritime board proper for the area covered by the plan").

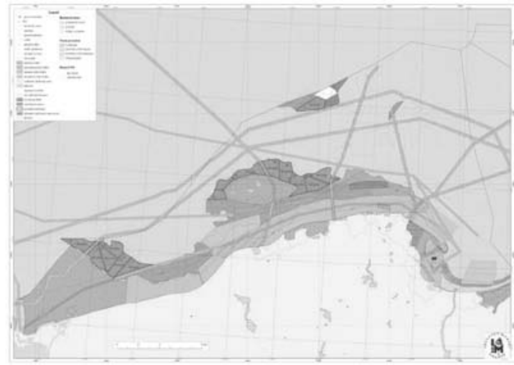

Figure 7. Instance of spatial planning in Polish sea areas (Cieślak A. 2008).

Due to lack of practice in the scope of making similar plans in sea areas, it was necessary to solve a number of problems pertaining to planning materials, graphic and letter markings concerning the intended use of the areas (in particular the economic zone constituting a part of international waters), requirements related to the content records of plans and many others.

Work undertaken for solving those problems continued until September 2005. In October 2005 the order draft was submitted for social and interdepartmental coordination. In November 2005 the department had remarks reported by the Society of Polish Town-Planners, the National Town-Planners' Chamber and the Architects' Chamber of the Polish Republic, remarks reported by the departments, and also the opinion of the Governmental Legislature Centre. In conclusion of the GLC's opinion, part of the records related to procedures of preparation, passing and accepting plans of sea areas' spatial development should have been legally regulated (Grabarczyk C. 2008).

After change of government and calling of independent Ministries, of Construction and of Sea Economy, work was suspended for two years. Legislative work was resumed late in 2007. In June 2008 an act draft was submitted for public agreement, related to amending building regulations, act on planning and spatial development and some other acts, where in Chapter 4a "Spatial Planning in Sea Areas" the requirement was fulfilled pertaining to the regulation of procedures of accepting sea areas' spatial development plans (Grabarczyk C. 2008).

In article 49g of the above-mentioned act draft an amended authorisation was included concerning the scope of subject plans: "The minister proper for matters of sea economy, in cooperation with the minister proper for matters of construction, spatial and housing economy, shall determine by way of order the required planning scope for spatial development of sea areas in the textual and graphic parts, with particular consideration of planning materials, source data and other applied data created in the process of planning, the standard of metadata for spatial data, used and created in the process of planning patterns, applied markings, symbols and terminology and the way of documenting planning work".

In connection with the above, after the parliament passes the above-mentioned act draft, the order draft determining the planning scope of sea areas' spatial development, in accordance with delegation of article 49g, after conducting the legislative process will be submitted for signing by respective ministers (Grabarczyk C. 2008).

6 CONCLUSIONS

The experience so far in the scope of spatial planning indicates a general need for preparing such plans on sea areas in an identical way as for land areas. Priorities should be established and planning scope determined. Considering the state of marine shipping and its development trends towards increasing the size of vessels and the frequency of their callings, it is a priority in the range of safety to ensure a transparent system of basic shipping routes.

The securing of water areas with shipping routes should be based on an analysis of vessel traffic so far, the planned development of ports and assumptions concerning the size of ships handled. The effect of hydrometeorologic conditions and emergency situations should also be taken into consideration. Insufficient planning of shipping routes now may cause potentially dangerous situations in future or simply increase the accident rate.

The process of agreeing and consulting initial proposals of spatial development planning should take its course inside the structures of the coastal state and with neighbouring states. An example of negotiating such a plan between Germany and Poland does not make one optimistic. Purely political reasons not related to the subject matter are stressed and the interests of the neighbouring country are not taken into consideration.

In accordance with the trend prevalent in EU countries, serious thought should be given in Poland concerning structural changes in maritime administration, aiming at separation of public and legal functions from economic activity, which might bring out and clear the matters connected with the spatial management of sea areas. An example of maritime administration structure has been presented in study (Hajduk J. & Rajewski P. 2004).

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

1.5 e-Navigation and the Human Element

D. Patraiko & P. Wake
The Nautical Institute, London, UK

A. Weintrit
Gdynia Maritime University, Gdynia, Poland & Polish Branch of the Nautical Institute

ABSTRACT: e-Navigation is an IMO initiative defined as "the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment". IMO has dictated that e-Navigation should be 'User Need' led and take into account the Human Element. This paper will explore some of the Human Element issues within e-Navigation and stress that for enhancement of safety, security and environmental protection, the decision maker must be supported not only by the technology, but importantly with effective procedures and training.

1 BACKGROUND

The concept of e-Navigation was first introduced to the IMO in 2006 at the 81st session of the Maritime Safety Committee (MSC 81 – May 06) at which time the committee was requested to adopt this vast new project as a work programme based on a compelling need which remains as:

There is a clear and compelling need to equip shipboard users and those ashore responsible for the safety of shipping with modern, proven tools that are optimized for good decision making in order to make maritime navigation and communications more reliable and user friendly. The overall goal is to improve safety of navigation and to reduce errors. However, if current technological advances continue without proper coordination there is a risk that the future development of marine navigation systems will be hampered through a lack of standardization on board and ashore, incompatibility between vessels and an increased and unnecessary level of complexity.

At that time, the Secretary General of the IMO, Efthimios Mitropoulos who has become a champion of the e-Navigation concept warned that the role of the mariner must not be relegated to that of a 'monitor' and urged the Committee to take into account the Human Element and all it's frailty when developing the various aspects of e-Navigation.

To support this expectation, it was made clear from the beginning that e-Navigation should be 'user needs led' rather than led by technologists or regulators.

During the period of 2006–2008, the IMO e-Navigation Correspondence Group (CG) supported by organisations such as the IALA and The Nautical Institute carried out an international exercise to identify these needs. Potential users of e-Navigation both afloat and ashore were contacted and asked to identify what their needs were in terms of harmonised collection, harmonised integration, harmonised exchange, harmonised presentation and harmonised analysis of maritime information onboard and ashore by electronic means.

It is worth noting that this may have been the largest user needs analysis ever conducted in the maritime industry, and many lessons should be learned from this experience. In particular, most end users are not practiced in articulating their needs well, and tended to identify what they had and what they liked. This then required a good deal of analysis to distil the 'need' from the 'like'.

2 USER NEEDS

The 'User Needs Analysis' as conducted through the IMO e-Navigation CG examined hundreds of feedback forms from around the world and categorised these into needs of the generic SOLAS class ship users and the needs of generic shore authorities.

Much effort was put into analysing the needs from descriptions of what was already in use, and quite importantly, to take out any reference to existing technologies. For example there is a need to identify and track a target in order to prevent a collision, rather than there being a 'need' for a Radar with ARPA (although it is recognised from a practical point of view that in the short term Radar will certainly be a key tool within the e-Navigation concept).

From these two analyses of shipboard and shoreside needs, it was established that there were common 'high level' needs and these were consolidated, presented, and ultimately accepted by the IMO (MSC 85 – Dec 08) as the basis of an e-Navigation strategy.

These consolidated user needs are reproduced here with *italic* text used to emphasise some of the major Human Element issues defined within e-Navigation.

2.1 *Common maritime information/data structure*

Mariners require information pertaining to the planning and execution of voyages, the assessment of navigation risk and compliance with regulation. This information should be accessible from a single integrated system. Shore users require information pertaining to their maritime domain, including static and dynamic information on vessels and their voyages. This information should be provided in an internationally agreed common data structure. Such a data structure is essential for the sharing of information amongst shore authorities on a regional and international basis.

2.2 *Automated and standardized reporting functions*

E-navigation should provide automated and standardized reporting functions for optimal communication of ship and voyage information. This includes safety-related information that is transmitted ashore, sent from shore to shipborne users and information pertaining to security and environmental protection to be communicated amongst all users. Reporting requirements should be automated or pre-prepared to the extent possible both in terms of content and communications technology. Information exchange should be harmonized and simplified to reduce reporting requirements. It is recognized that security, legal and commercial issues will have to be considered in addressing communications needs.

2.3 *Effective and robust communications*

A clear need was expressed for there to be an effective and robust means of communications for ship and shore users. Shore-based users require an effective means of communicating with vessels to facilitate safety, security and environmental protection and to provide operational information. *To be effective, communication with and between vessels should make best use of audio/visual aids and standard phrases to minimize linguistic challenges and distractions to operators.*

2.4 *Human centred presentation needs*

Navigation displays should be designed to *clearly indicate risk and to optimize support for decision making*. There is a need for an integrated "alert management system" as contained in the revised recommendation on performance standards for Integrated Navigation Systems (INS) (resolution MSC 252(83)). Consideration should be given to the use of decision support systems that *offer suggested responses to certain alerts*, and the integration of navigation alerts on board ships within a whole ship alert management system. Users require uniform and consistent presentations and operation functionality to *enhance the effectiveness of internationally standardized training*, certification and familiarization. The concept of S-Mode[1] has been widely supported as an application on board ship during the work of the Correspondence Group. Shore users require displays that are fully flexible supporting both a Common Operating Picture (COP) and a User Defined Operating Picture (UDOP) with layered and/or tabulated displays. *All displays should be designed to limit the possibility of confusion and misinterpretation when sharing safety-related information. E-navigation systems should be designed to engage and motivate the user while managing workload*.

2.5 *Human machine interface*

As electronic systems take on a greater role, facilities need to be developed for the capture and presentation of information from visual observations, as well as user knowledge and experience. The presentation of information for all users should be *designed to reduce "single person errors" and enhance team operations*. *There is a clear need for the application of ergonomic principles both in the physical layout of equipment and in the use of light, colours, symbology and language*.

2.6 *Data and system integrity*

E-navigation systems should be resilient and take into account issues of data validity, plausibility and integrity for the systems to be robust, reliable and dependable. Requirements for redundancy, particularly in relation to position fixing systems, should be considered.

2.7 *Analysis*

E-navigation systems should *support good decision making, improve performance and prevent single person error*. To do so, shipboard systems should include analysis functions that support the user in complying with regulations, voyage planning, risk assessment, and avoiding collisions and groundings including the calculation of Under Keel Clearance (UKC) and air draughts. Shore-based systems should support environmental impact analysis, forward planning of vessel movements, hazard/risk assessment, reporting indicators and incident prevention.

Consideration should also be given to the use of analysis for incident response and recovery, risk assessment and response planning, environment protection measures, incident detection and prevention, risk mitigation, preparedness, resource (e.g., asset) management and communication.

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[1] S-Mode is the proposed functionality for shipborne navigation displays using a standard, default presentation, menu system and interface.

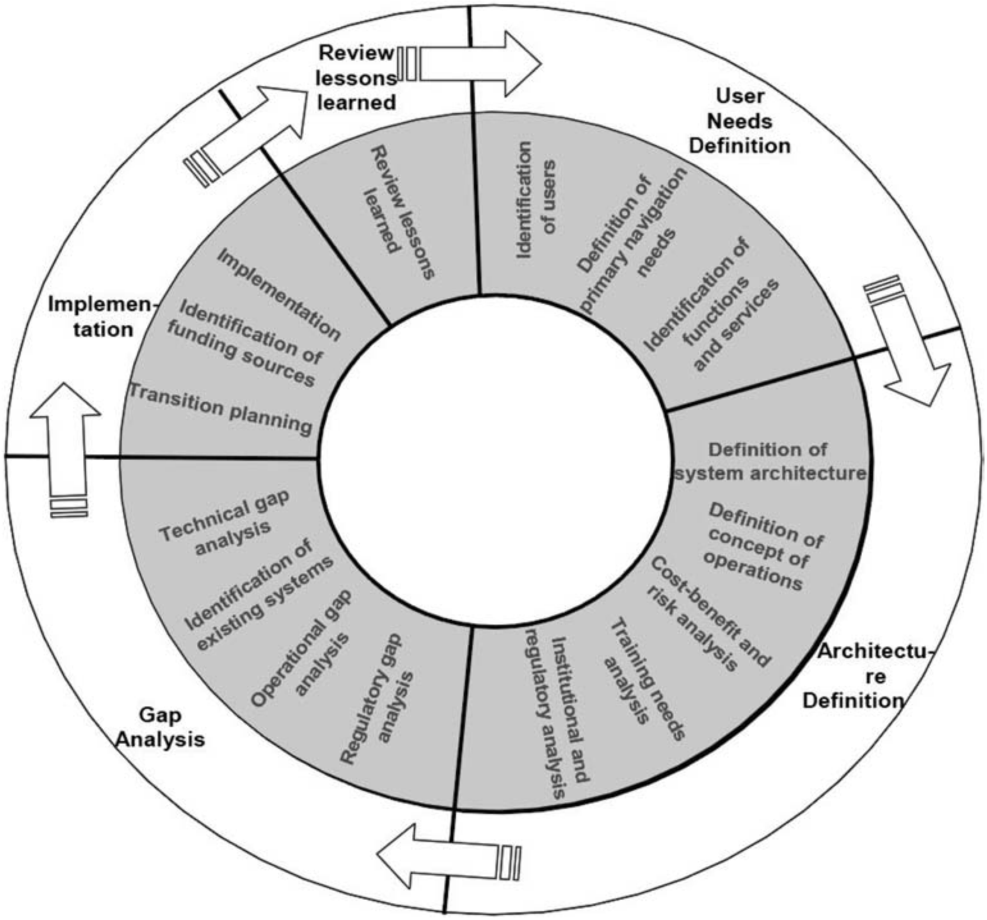

Figure 1. Potential components of an e-Navigation implementation plan [IMO NAV 54/WP.6 2008].

2.8 *Implementation issues*

Best practices, training and familiarization relating to aspects of e-navigation for all users should be effective and established in advance of technical implementation. The use of simulation to establish training needs and assess its effectiveness is endorsed. E-navigation should as far as practical be compatible forwards and backwards and support integration with equipment and systems made mandatory under international and national carriage requirements and performance standards. The highest level of interoperability between e-navigation and external systems should be sought where practicable.

It is clear from these 'user needs' that there is a major emphasis on supporting the decision making process, not only by better technology, but through the establishment of best practices for the use of such technology and the training needs that apply to both the technology and the procedures.

It should also be noted that needs such as "*E-navigation systems should be designed to engage and motivate the user while managing workload*" are easier said than done and will require a tremendous amount of research and testing to achieve.

3 S-MODE

In the description of 'Human Centred Presentation Needs' it is stated that "Users require uniform and consistent presentations and operation functionality to enhance the effectiveness of internationally standardized training, certification and familiarization."

The Nautical Institute through consultation with its members has proposed a concept called S-Mode to address this need for the shipboard users.

The concept calls for all navigation systems in the future to have a standard 'S-Mode' switch, that when activated defaults to a standard display (e.g. head-up display, relative vectors, etc.) that can then be fully manipulated through a standard menu system where functions (such as for changing range, aspect, or using EBL/VRM, parallel indexing, …) would all be standardised, and the input interface with the systems (perhaps track ball, joystick or keyboard) would be standard. The concept for S-Mode is to create standard features. S-Mode is not envisaged as a simplified or restricted display mode, but instead would offer a high degree of functionality. However, the use of these functions would all be standard and anyone trained in the use of S-Mode would therefore be competent and confident to make the best use of navigation systems on any ship so equipped.

S-Mode may also incorporate provisions for the use of personal settings that may be stored within the system or on a personal memory device that would allow a pilot or mariner to rapidly configure the system to their preferred settings, overlay custom display features or give access to specialist information.

S-Mode would not preclude the use of other navigation features that could be provided by a manufacturer. These may be designed to take advantage of cutting edge technology, advanced programming or innovative presentation options that would be operated outside of S-Mode.

It is the intention of The Nautical Institute to secure funding to implement a phased project approach to the development of S-Mode. The Nautical Institute considers it will be necessary for: the user needs of mariners to be defined; to work with industry to create mock-up variations; and then to test these variations using simulation and other techniques with representative bridge teams. After thorough testing and evaluation, the system and training requirements would be put forward to the International Maritime Organization for consideration. Further information about S-Mode is contained in (IMO NAV 54/13/1, 2008) which is a copy of the submission of the S-Mode proposal to the IMO Sub-Committee on Safety of Navigation July 08 (NAV 54).

4 PROFESSIONAL RELATIONSHIPS

One of the fundamental premises of e-Navigation is to create a 'wider area' navigation team that will facilitate better decision making by the sharing of information between ship's navigation team and all the shore-side support organisations. This is of course a valid objective, and if managed properly will create a more effective navigation team that minimises the risk of single person errors.

The maritime industry has of course spent a lot of effort during the past few decades learning how to implement effective teams and this has resulted in much discussion of effective Master/Pilot relationships; Bridge Team Management (BRM) training; and shipboard resource training. From this experience comes recognition that for teams to work effectively, it is absolutely essential that there be a common platform for communication (including language and terminology) and that there needs to be mutual professional respect between team members.

As e-Navigation develops and greater communication is established between mariners and shore authorities, will we have addressed these issues? At present, within a port that utilises VTS, it is usually the Pilot who acts as a communicator between the VTS staff and the shipboard staff. The Pilot has an established working relationship with the VTS staff, and while onboard, can make best use of interpersonal skills to establish a working relationship with the ship's crew (in an ideal situation). However how can we ensure that without this interpersonal interaction, the wide area navigation team will work well together?

Ongoing research by The Nautical Institute indicates that in order to communicate effectively and foster professional respect, clear procedures may have to be established possibly based on a far greater use of the IMO's Standard Maritime Communication Phrases (SMCP) and for training exercises to be conducted focusing on the various stakeholders within this evolving relationship. Even without the concept of e-Navigation, such issues will need to be addressed as the establishment of 'coastal surveillance' becomes more common and IALA develops the concept of Vessel Traffic Management (VTM) based on the management of traffic outside traditional VTS areas.

5 FURTHER RESEARCH

The success of e-Navigation will rely heavily upon the proper application of the Human Element throughout its development and implementation. The Nautical Institute believes that there are some major Human Element aspects that deserve further development and research to be done on an international basis to support the IMO's e-Navigation concept. These can be summarised as:

– Proper balance of information levels and workload on mariners and shore based operators.
– Effective display options to support good decision making (including the development of S-Mode).
– Tools and procedures for reducing 'rouge behaviour' or complacency and keeping the operator actively engaged in the process of safe navigation.
– Methods and procedures for reducing 'single person errors'.
– Optimum use of 'decision support systems' including the best use of alarms and alerts.
– Effective procedures for ship/shore communication and teamwork.
– Supporting decision making capabilities of individuals through self-esteem and confidence building.
– Ensuring that all technical developments within the concept of e-Navigation are supported by effective procedures and training.
– Developing effective tools for capturing and analysing user needs within the maritime industry.

It is recognised that much of this research and testing will best be done through using scenarios representing all appropriate stakeholders, and that the use of simulation may be a highly effective tool for testing, documenting and ultimately training for such aspects of e-Navigation.

6 CONCLUSION

e-Navigation is a broad concept that is aimed at enhancing navigation safety, security and the protection of the marine environment through the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means.

It is envisioned that e-Navigation will be a 'living' concept that will evolve and adapt over a long time scale to support this objective. During this time information will change, technologies will change, political and commercial objectives will change, and tasks will change. However it is unlikely that the need for safe and efficient seaborne transport will change significantly.

It is also certain that the safe and efficient transport will continue to rely on good decisions being made on an increasingly constant and reliable basis. Some decisions may be made with increased dependence on technology, but at some level we will always rely on good human decisions being made and therefore every effort needs to be made to apply an understanding of the Human Element at all stages, of design, development, implementation and operation of e-Navigation.

The Nautical Institute as the leading international body for maritime professionals will continue to use the resources of its members, branches, officers and staff to promote the effective application of the Human Element for e-Navigation and other industry developments, and invites all maritime professionals to join in this critical effort.

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1.6 Generation of Electronic Nautical Chart data for assessment of navigational safety in harbour and waterway design

K. Guan, C. Shi, S. Wu & T. Xu
Merchant Marine College, Shanghai Maritime University, Shanghai, China

ABSTRACT: Navigational simulator is widely applied in the assessment of Navigational Safety in the harbour and waterway design. According to the needs of ENC(Electronic Nautical Chart) data in the navigational assessment, this paper analyzes the source of ENC data, such as S-57 data, MVCF(Military Vector Chart Format) data and CAD(Computer Aided Design) data. An effective method of ENC data generation has been developed. Special techniques are investigated for generating ENC data, such as ENC data structure designing, chart data conversion, digitization method of raster images of CAD design drawing, optimization approaches and data integration methods. Software has been developed to edit the chart data with good performance. The technologies developed in this paper have been applied to more than 100 practical projects and successful results have been obtained.

1 INSTRUCTION

With the fast development of water transportation in recent years, significant projects of harbour and waterway increase constantly, and the traffic density in water areas also increases unceasingly. Usually the investments of many harbour projects are enormous and it was costly if some design mistakes could not be identified. Once the accident happens, the direct and indirect losses are inestimable. Hence, it is important to carry out the assessment of Navigational Safety in harbour and waterway design to ensure safety of navigation when the projects are implemented (Guan et al. 2005).

To assess the navigational safety of designing projects of harbour and waterway, ship-handling simulator is employed to carry out simulated tests in real time. Results retrieved from analysis of the test data are benefit not only for the navigational safety of the vessel, but also harbour and waterway facilities. The tests help reduce the expenses of the engineering experiment, and optimize the design of the project. The shiphandling simulator assessment can improve the economic benefits and competitiveness of the port. It can check out the potential capacity of the port and berths, and provide approaches to make fully use of the berthing ability of the port.

Usually the fast simulation of navigation is adopted, using the simulation system of two-dimensional (2D) display. The system is composed of the Electronic Chart Display and Information System (ECDIS) and the navigational Simulation Controlling System. The operator, who is shown a 2D chart display, use the keyboard to control the engine and the rudder. Multiple PC systems can be used carry out simulation tests of different operation mode at the same time to accelerate the assessment procedure.

In order to perform the simulation test described above, it is a very important step to generate the ENC data for the planning harbour and waterways. In this paper, approaches are studied to use various existing chart data sources and design data of harbour and waterway projects. A rational and fast method is developed for the generation of ENC data specifically for the assessment of navigational safety of harbour and waterways.

2 THE NEEDS OF ENC DATA IN NAVIGATIONAL ASSESSMENT

The work of the assessment of navigational safety in the harbour and waterway design include mainly:

1) Assessing the efficiency of navigation in the channel. The data, such as the channel width, water depth, navigational marks, etc. of the design waterway, are checked whether the requirements could be met for the navigational safety of the vessel with design tonnage under certain hydrological and meteorological conditions. This step is performed mainly through simulator operations, obtaining the width of the vessels' paths and the tracks of vessels out of control or drifting.
2) Assessing the capacity of berthing in the port. The data to be assessed include the size and water depth of manoeuvring area of the design quay. Simulator

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checks are carried out to make sure the requirements are met for safe berthing operations of the vessel with design tonnage under certain hydrology meteorological conditions. (Qian 2003).

In order to meet the needs of the navigational assessment, the ship-handling simulator should provide the ENC data with large scales. Those data should be organized with a rational structure. The general precision of the ENC data is required to be within the range of meter. And it is required that ENC data must include the following details,

1) Lands and islands;
2) Quays, docks, bridges and inshore facilities;
3) Beaches, depths of water, depth contours and bottom characteristics;
4) Channels, anchorage, security area and sea floor pipelines;
5) Obstacles;
6) Aids to navigation;

For the ENC database used in the assessment, the following demands should also be considered,

1) Good compatibility and expansibility,
2) Adapting of the standard electronic chart data structure,
3) Adapting of the data of the design drawings of the project,
4) Efficiency and costs,
5) Maintainability and portability.

Meanwhile, it must be easy to search and revise, and in a hierarchical structure to raise the speed of data processing.

3 ANALYSIS OF THE SOURCES OF ENC DATA

The assessment of navigational safety in the harbour and waterway design usually assesses the project that is going to be implemented, or in progress of the design phase. There is, therefore, no ready-made nautical chart to be used. We can only combine the design drawings of the project and the existing nautical chart of water areas to set up specific ENC specific database to meet the needs. The sources of the ENC data can include the existing paper nautical chart, S-57 electronic nautical chart data, MVCF electronic nautical chart data, CAD project design drawings and satellite remote sensing image, etc. As to the existing electronic nautical chart data, corresponding format change is necessary, changing the standard S-57 format data into the system defined format data. Special processes are needed for other sources such as paper nautical chart, satellite images and CAD design drawings, etc.

3.1 *S-57 data*

The Standard IHO (International Hydrographic Organization) S-57 is the most popular ENC data worldwide. It is designed to permit the exchange of data describing the real world. The data produced is organised into named structures. Usually, more than one object is involved in an exchange. Therefore, since an object is structured into a record, an exchange is comprised of more than one record. To facilitate this, records are grouped into files. The set of information which is finally exchanged is called an exchange set (IHO. 2000).

This standard defines a set of records from which an exchange set can be built.

These records fall into five categories:

1) Data Set Descriptive Record: Containing information about the coordinate system, the projection, the horizontal and vertical datum used, the source scale and the units of height and depth measurement, and information about the origins of the data set.
2) Catalogue Record: Containing the information required to allow the decoder to locate and reference files within the entire exchange set. This part can be compared with a table of contents. It also contains information about special relationships between individual records within the exchange set.
3) Data Dictionary Record: Containing the description of objects, attribute and attribute values used in an exchange set.
4) Feature Record: Containing the non-locational real-world data.
5) Spatial Record: Containing the locational data. They may be of types of vector, raster or matrix. An exchange set may contain a mixture of the different spatial record types. Among them, vector records include the information about the coordinate geometry related to the feature records, including spatial attributes, topological relationships and update instructions. Vector records may be of types node, edge or area.

S-57 data can be obtained from the nautical chart publishing department.

3.2 *MVCF Data*

MVCF is an abbreviation of the Military Vector Chart Format, which is the digital nautical chart interchange standard of China. It possesses the characteristics of the following:

1) It is a kind of geographical datum model without the topological relation, supporting the fast display and easy editing of the data;
2) It supports the index file. The structure of the data is succinct;
3) It supports point, line, polygon and annotation notes. Therefore it supports the exchange of the whole nautical chart data elements;
4) Attribute is supported. The attribute of the vector is stored in dBASE format file, and the attribute record is the one-to-one correspondence with vector record.

MVCF data file is organized by the sheet of paper chart. It adopts the catalogue structure. The catalogue name is the same as the serial number of digital nautical chart. MVCF data compose of four files: basic file, shape file, index file and attribute file. Among them, the shape file is a variable length record file of direct access. It contains the coordinate position data of the nautical chart. Index file contains describe the offset of the beginning record corresponding shape file record. The attribute file is in dBASE format structure. It contains the attribute of the vector data. The shape file record is one-to-one correspondence with the attribute file record.

MVCF data can be obtained from the Navigation Support Department of the Navy Headquarters. The nautical charts published cover the whole coast area of China.

3.3 *CAD engineering design drawing*

Usually, software of AutoCAD is employed in making the drawings of design projects of harbour and waterway. These drawings include data of water areas and land-based areas, especially the newly-built objects, such as quays, docks, bridges, channels and navigation marks, etc. These designs are the target of the safety assessment. The data may also include harbour building, shipyard workshop and coastline, etc., which are not as critical in safety assessment. Hence, the data that we care about are only part of the engineering drawings for the relating water areas, and it is unnecessary to change the whole CAD file directly. By retrieving part of the data from the drawings, information redundant can be avoided.

In China, the domestic coordinate system, BJ-1954, is generally used in the design drawings. Additional conversions should be made to ensure compatibility with the coordinate system, WGS-84, that ECDIS adopts. In our research an approach is developed for the processing of the drawings. The CAD data file is printed to a JPG image. Then, with digitization technology, vectorization operation of the parts we need is performed. In order to improve the processing efficiency, we only concern the newly-built relevant objects, such as quays, docks, manoeuvring areas, channels and navigation marks, etc.

3.4 *The satellite remote sensing image*

The satellite remote sensing is the new technology to obtain the information such as resource, environment and calamity in the coastal areas. It has some conspicuous advantages, such as large-scale, high efficiency, synchronization, high frequency of dynamic observation and so on. With the fast development of the remote sensing and computer technology, the satellite remote sensing can replace the survey artificially with a great extent. It becomes a important data source of the digital chart. It is a kind of very economical and practical method to use the satellite remote sensing image of high-resolution. By digitization, Data of coastlines, quays, berths and buildings can be obtained from satellite images.

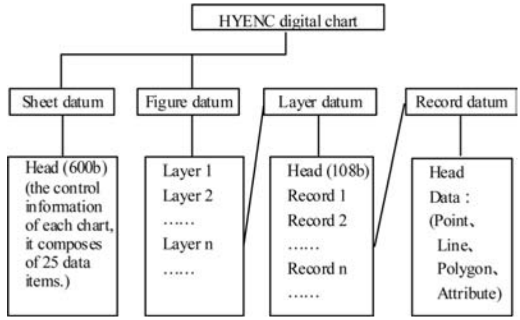

Figure 1. The structure of HYENC data.

4 THE STRUCTURE OF ENC DATA

To meet the requirement of the navigational assessment, one structure of reasonable ENC data has been developed and named as HYENC (Electronic Nautical Chart Local Defined). Conciseness and memory saving are considered, and it is convenient for transformation, renewal and maintenance, as well as fast display.

HYENC data structure defines that each file represents one nautical chart. The file includes sheet data and figure data. The sheet data on the head of the file contain 600 bytes for the control information of each chart, and they are divided into 25 data items. The figure data are variable length records of direct access, recording the data of layers of each chart, and per layer of data includes the head data of 108 bytes and the records of variable length. The record counts and type are stored in the sheet data. The structure of HYENC data is shown as Figure 1.

The sheet data includes information such as the name, range, scale, coordinate system of the nautical chart. By this information, chart search can be performed rapidly, and chart panning and seamless splicing can be realized. The figure data is such structured that it helps the hierarchical display of the chart, as well as convenience for combining, adding and deleting relative information.

5 THE METHOD OF ENC DATA GENERATION

5.1 *ECDIS coordinate system and conversion*

To display the chart on the computer screen, it needs converting Mercator projection coordinate into computer screen coordinate. When performing chart work on ECDIS, we need to convert computer screen coordinate into geographic coordinate. Conversion and calculation of all kinds of coordinate in real-time for the display and operation can influence system performance of ECDIS.

For fast display, the ENC stores the point assemble data in longitude and latitude coordinate. Longitude data is in the unit of minute, and latitude in meridional parts. When displaying the chart on the computer screen, the time for converting latitude into meridional parts can be saved, improving the speed of displaying.

In ECDIS, the point of left bottom is taken as the origin of coordinate with display format of north up. We establish coordinate system that the OY axis is upwards, OX axis rightwards. Suppose that a geographical coordinate point, $M_0(\varphi_0, \lambda_0)$, corresponds to screen coordinate point, $P_0(y_0, x_0)$, then any geographical coordinates and screen coordinates may be converted using equation (1) and (2):

Longitude λ converts into x:

$$x = x_0 + (\lambda - \lambda_0) \times f \tag{1}$$

Latitude φ converts into y:

$$y = y_0 - (\varphi - \varphi_0) \times f \tag{2}$$

where f is a scale, expressing the ratio of meridional parts of geographical coordinate to the display screen coordinate.

By the similar manner, it is easy to convert screen coordinates into geographical coordinates.

When performing zoom in, zoom out, drag and other operations, we can fast convert coordinates, and display ENC figure on the computer screen. Meanwhile, we use the screen clipping algorithm to filter the ENC data. It filters out the data beyond screen range, and improves the displaying speed of ECDIS.

In the ECDIS, the geographical position is expressed in longitude and latitude coordinates, i.e. degree, minute and second. Then the corresponding algorithm of mutual conversion between latitude and meridianal parts may refer the paper (Zhang 2003).

5.2 *The procedure of ENC data conversion*

For the assessment of navigational safety in the harbour and waterway design, the design department supplies the project design drawing in CAD format. We must use another method to obtain other data such as the nearby coastline and channel. Through the analysis described above, these data can be obtained from sources such as paper chart, S-57 format data, MVCF format data, remote sensing satellite images and CAD project design drawings, etc. These data are mainly divided into two kinds, the digital ENC data and raster image. For ENC data, we need compile programs to apply converting of S-57 format data and MVCF format data, while a digitalization is need for paper charts, remote sensing images and CAD project design drawings. Then we integrate all data into one ENC data file which serves the simulation assessment. The converting procedures are illustrated in Figure 2.

5.3 *Digitization of raster images*

Digitization is a very important step in the procedure described above, i.e. use certain apparatus and software to digitize raster image and convert them into vector data. Hu (1999) recommended a method of

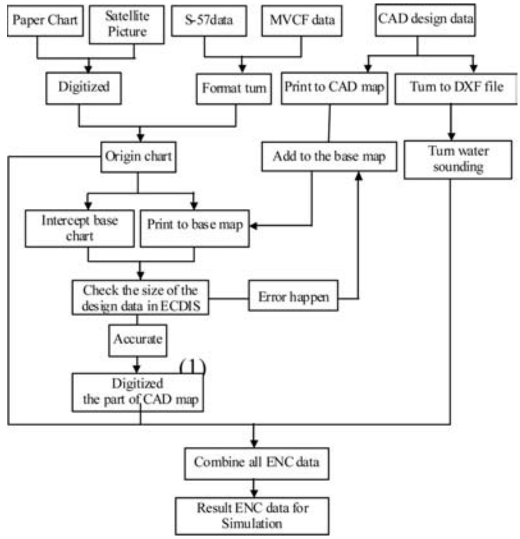

Figure 2. The procedure of data converting.

using digitizer to convert paper chart. This method utilizes digitizer and corresponding software of collecting ENC data together, which convert raster data into vector data. The method which relies on circumscribed digitizer, a paper chart can only use on one machine at a time. It is kinds of complicated inefficient to convert the data, and inconvenient to modify latter data. The approach is kinds of inefficient and can hardly meet the requirement of project research in the time limit.

A PC-based ENC data editor system is developed to meet our needs. It uses the mouse and interface software to digitize raster images. Firstly, it is important to determine the key point position i.e. its longitude and latitude, the coordinates of the screen of southwest and northeast point. We can obtain the coordinates from the paper chart or the satellite remote sensing image. After determining the key point, we can display the raster image in PC-based ENC data editor's system, and then use the mouse to collect manually the point-line-face data of the chart. The system automatically converts a mouse position of the screen coordinate into geographical coordinate, and save the coordinate data into the data file.

We adopted layered storing and displaying technology of ENC data. We can digitally compile paper chart on several PC at the same time, and collect all the data into one file finally. Thus it can improve the speed of making ENC data, and shorten development period. Furthermore we may add, delete, edit the data randomly and maintain the data conveniently. Figure 3 illustrates the ENC data editor's system software interface.

If the image is the CAD design drawing, we need to convert the format of the CAD file into *.JPG image. Then The ENC data editor's system software interface is the image processing software such Photoshop is used to superimpose the image with the base map.

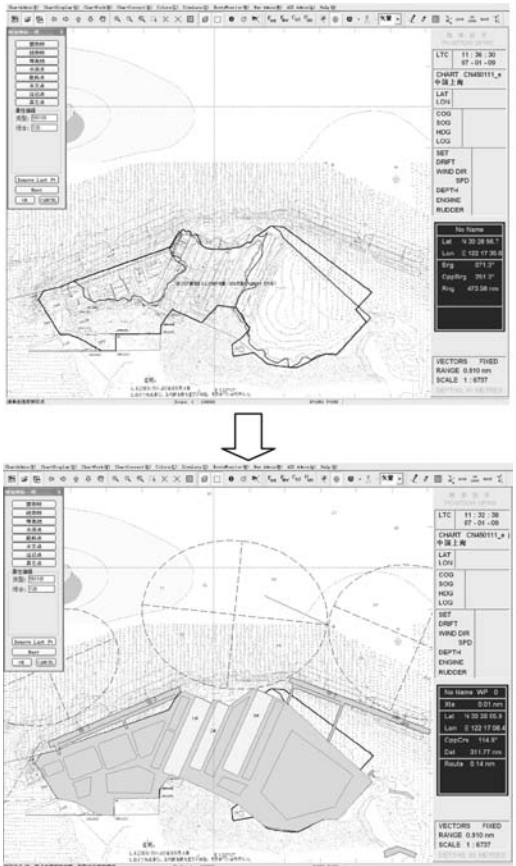

Figure 3. ENC data editor's system.

The JPG format image needs to be zoomed in or out in the same proportion. Firstly we match the base map and the CAD design drawing. Then the length of the quay or size of turning circle area is measured by using the digitized system software. The size is compared with the dimension of CAD design drawing, and the difference proportion is calculated. Secondly, adjust the size of JPG image in the proportion until the two images are identical in size. At last the composite image can serve as digitized base map. When digitizing the image, we only need to choose useful information, for example, quay, dock, newly-increased coastline, turning area, channel line, designed anchorage, navigation mark, and depth of water and note information.

5.4 *Generation of water depth data*

Water depth is an important parameter in the assessment of navigational safety in the harbour and waterway design. The design water depth of channels or turning area should ensure enough Under Keel Clearance (UKC) for vessels. The designer supply CAD design drawings that includes survey data of depth of water. We can obtain water depth data according to the digitized method described in Section 5.3. But it is relatively heavy workload to input a large amount of depth of water manually. So we plan to obtain water depth data with data conversion method. Firstly export the CAD drawing format file (*.DWG) as Drawing Interchange Format file (*.DXF). Then extract water depth data from the file with certain algorithm, and keep a series of point, P (x, y, z), where the coordinate x and y express plane coordinate, and z express the depth of water, into a collection. Finally convert the point collection into ENC water depth data.

If there are no newly surveyed data, water depth can be obtained from the present paper chart. We can convert present S-57 format data or MVCF format data. Water depth data of S-57 format denote in SG3D record, while water depth data of MVCF format are specially stored in the sounding layer. In the ENC data editor's system, we can use the mouse to add, delete, and edit water depth data. Based on present data of water depth, neural network technology is used to carry out difference calculation (Shi 2004). While navigating in the simulation area, water depth nearby the ship is detected in real-time, determining whether the water depth of the channel meets the demands or not.

5.5 *Data combining and correction*

In order to ensure the maintainability of ENC data, we adopt layered processing technology, which classifies point object, line object and area object based on different characteristic of ENC data. For example water depth, navigation mark, marks on the bank are inducted as point object; and coastline, depth contour and submarine cable, etc are inducted as line object; land, island and quay, etc. are inducted as area object. Because of data the layered structure, we can integrate pieces of ENC data easily. There are two kinds of situations. One adds data of additional map directly to base map data, at the same time adjust the sheet data of base map, thus additional map will overlay on the base map. Second method is to integrate the index number of layer data of additional map and layer data of base map corresponding to the index of layers.

In order to maintain ENC data and develop ENC editor system, when we edit point, line and area object, only the mouse is needed to finish adding, correcting, deleting of the point collection, and to edit attributes. Several computers can work simultaneously on one chat, and the generated data are put together finally, improving the efficiency of making ENC data.

6 CONCLUSIONS

Navigational simulator is widely applied to assessment of navigation safety in harbour and waterway design at present, but the ENC data are the fundamental element of the simulation. The ENC data produced by above described method can be applied to two-dimension ship handling simulation system. Meanwhile, it is the source of the simulation radar echo data and coastline, port building and topography of three-dimension visual system in large ship simulators. In this way, we can make all data totally identical, ensuring reliability of the simulation result. Software has been developed to edit the chart data with good performance. The technologies developed in this paper have been applied to more than 100 practical projects and successful results have been obtained.

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1.7 Study on shipping safety strategy based on accident forecast model

X.Y. Meng, Y.M. Bai & X.J. Han
Dalian Maritime University, Dalian, China

ABSTRACT: The factors which would cause shipping accidents are analyzed in detail and a model which can forecast shipping accidents is studied in this paper. During navigation, all the factors are integrated and calculated in this model which then estimate and speculate on the risk degree of collision for the own ship. Finally, the risk level and the possibility of shipping accidents can be forecasted in real-time. The proposed accident forecast model can estimate the possibility of collision with other ships or objects in a specific domain. Meanwhile, the external environment such as weather, stream, *etc.* is taken into account in the model. Besides, the validity of navigators' orders can also be evaluated in the model which consequently can forecast different kinds of shipping accidents effectively in that most of the factors which cause shipping accidents have been involved in the proposed model. With the accident forecast model, the shipping safety would be improved greatly. A practical example demonstrates the effectiveness and superiority of the proposed strategy.

1 INTRODUCTION

Although modern watercrafts have been equipped with advanced facilities, such as satellite navigators, anti-collision radars, electronic charts, and automatic cabins, *etc.*, the occurrence of shipping accidents is still frequent. Therefore, the IMO organization and many other organizations pay more attention to the shipping safety. According to IMO organization's analysis results, there are three main reasons resulting in shipping accidents in recent years:

① the failure of equipments on watercrafts;
② the influence of navigation environments and conditions;
③ and, human factors.

The proportion of these three factors to the whole is shown in Fig. 1, from which it can be seen that up to eighty percent of shipping accidents are directly or indirectly caused by human error. Under the complicated circumstance, navigators lacking of watch have poor capability of dealing with emergency, poor qualities and little sense of duty, as well as cannot master traffic rules on the sea well. Hence, misoperation will occur. In order to guarantee the safety of shipping, we should pay more attention to human factors where not only the quality of navigators and their ability of dealing with emergency would be developed, but also the latest modern technology for prediction of shipping accidents and blocking the wrong order or misoperation would be adopted. Consequently, a shipping accident forecast model is developed in this paper. Furthermore, a method of the shipping accident prediction and control is studied based on the proposed model.

2 ANALYSIS OF THE REASONS IN SHIPPING ACCIDENTS

The shipping system is comprised of watercrafts, human and the navigation circumstance. Due to the particularity of carriers and conditions, the characteristic of shipping systems which are complicated

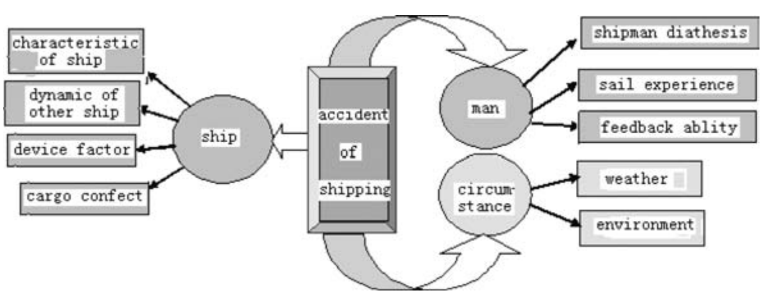

Figure 1. The influence factors of shipping accident.

systems is multi-category, multi-layer, multi-attribute and multi-rule. Shipping accidents can be classified into the following types, collision, grounding, striking, heavy weather, fire & explosion, foundering, missing, and engine failure, *etc*. Risk during navigation mainly results from three factors: a) collisions with other objects (static or moving), b) the change of external environments (such as typhoons, tidal waves, fogs, and other disasters), and c) wrong orders sent by navigators (including misoperations). These three factors of the system also have many components which are shown in Fig. 1. In recent years, new challenges encountered in shipping systems are mainly as follows:

1) With the trend that ships become larger and larger, as well as more and more rapid, the inertia of a ship becomes larger, and therefore it is more difficult to manipulate the ship.
2) With the world economy incorporating and increasing, the quantity of ships proliferates. Together with the progress of ocean oil field exploring and sea culture, the navigation density inshore becomes higher. Hence, high risk would be taken when a ship navigates in the inshore area or on dense lane.
3) The abnormal change of the weather such as fogs and typhoons, etc., critically influences the navigation condition.

In order to cope with these problems, the technology and techniques for shipping safety are required to be studied and developed urgently. Especially, the human factor should be highlighted. In this paper, a shipping accident forecast model is proposed to avoid and control various accidents.

3 THE SHIPPING ACCIDENT FORECAST MODEL

3.1 *Structure of the model*

Nowadays, there are many kinds of models describing the ship motion. Among them, models correlated to the shipping safety are mainly: 1) OD traffic flow model (Fuji J. *et al.* 1971), 2) ship field model (Davis P V. *et al.* 1982, Goodwin E.M. 1975), and 3) DCPA (distance of close point of approaching) and TCPA (time of close point of approaching) model (Zheng Zhongyi *et al.* 2000). These models describe various characteristics of the shipping safety from different points of view. They have some advantages and are applied to large scales of areas. However, they cannot essentially solve the problems of the shipping safety. In this paper, a shipping accident forecast model which integrates each kind of factors influencing the shipping safety is proposed. As the output of the model, the risk degree is the concept of the possibility that accident will occur.

The shipping accident forecast model can be expressed as follows:

$$W(n) = U_T(U_{dT}, U_{tT}) \cap M_{i,j} \cap H_n \tag{1}$$

where,
$W(n)$ —— the output of the forecast model which is defined as risk degree;
H_n —— the evaluated influence degree of navigation environments;
U_T —— the risk degree of collision with encountering targets;
$M_{i,j}$ —— evaluation results of the operation instruction (telegraph orders and rudder orders).

The output of the accident forecast model is determined by three items which correlates to three main aspects causing shipping accidents respectively. The first item in the model is $U_T(U_{dT}, U_{tT})$, which interprets the encounter probability and the risk degree of collision. The second item is the evaluation to the validity of orders sent by navigators. The third item is the degree of influence on the shipping safety while external conditions vary. The output $W(n) \in [0, 1]$ suggests that the ship has no danger while $W(n) = 0$ and the ship is in danger while $W(n) \neq 0$. The larger the output $W(n)$ is, the higher the risk degree is.

The inputs of the model mainly come from the scanning information of the ARPA, other navigation operation instructions, parameters of velocity and course, and other related information from sensors (wind velocity and ship draft, *etc.*). Integrating this information, the forecast model evaluates the risk degree in real time.

3.2 *Risk degree of collision*

The risk degree of collision with encounter targets U_T involves the space collision risk U_{dT} and the time collision risk U_{tT}. The space collision risk mainly includes the *DCPA*, ship fields, the fuzziness of domain boundary, the orientation of encounter targets, observation errors in the *DCPA*, *etc*. According to the velocity and course of the own ship and encounter objects, the shortest encounter distance between them is $DCPA = R_T \bullet \sin(\varphi_R - \alpha_T - \pi)$. After the safety encounter domain d_1 and the safety passing distance d_2 are determined, the fuzzy set U_{dT} of the space collision risk can be obtained. The membership function u_{dT} of U_{dT} is defined as follows:

$$u_{dT}(DCPA) = \begin{cases} 1, \text{if } |DCPA| < d_1 \\ \left(\dfrac{d_2 - |DCPA|}{d_2 - d_1}\right)^2, \text{if } d_1 \leq |DCPA| \leq d_2 \\ 0, \text{if } |DCPA| > d_2 \end{cases}$$

The time collision risk mainly expresses the relative velocity, distance, velocity ratio between two ships, the length of own ship, and maneuvering performance, *etc*. According to the relationship between encounter and movement of ships, the encounter time between the own ship and targets is given by

$$TCPA = R_T \bullet \cos(\varphi_R - \alpha_T - \pi) / v_R \tag{2}$$

After the extreme time t_1 for sending a rudder order and the time t_2 for ensuring the relative safety distance between two ships are determined, the verifying domain of *TCPA* is U_t and the fuzzy set of the time collision risk is U_{tT}, of which the corresponding membership function u_{tT} is defined as follows:

$$u_{tT}(DCPA)=\begin{cases}1, \text{if } TCPA\le t_1\\ \left(\dfrac{t_2-TCPA}{t_2-t_1}\right)^2, \text{if } t_1<TCPA\le t_2\\ 0, \text{if } TCPA>t_2\end{cases}.$$

The collision risk between ships is the synthesis of the space collision risk and the time collision risk. In the domain U, the ship collision risk is a set of U_T, and we have

$$u_T = u_{dT} \oplus u_{tT} \tag{3}$$

The above-mentioned synthesis operator "⊕" means that,

So long as $u_{dT}=0$ or $u_{tT}=0$, we have $u_T=0$. Otherwise, if $u_{dT}\neq 0$ and $u_{tT}\neq 0$, $u_T=\max(u_{dT},u_{tT})$.

3.3 *Determination of the impact item of environment conditions*

The navigation environment factors involve the weather, hydrology and lane conditions. For the sake of simple computations, the environment influence parameter H_n (influence degree of navigation environment) is mainly determined by the wind velocity and the wind direction measured by wind gauges, and determined by rocking parameters which are derived from the ship's draft of each shipboard. The function is given by

$$H_n=\left(\frac{f_n}{f_{\max}}\otimes\frac{l_n}{l_{\max}}\right)$$

where f_n is the wind velocity, $f_{\max}$ is the maximal wind power, l_n is the rocking height, $l_{\max}$ is the maximal rocking height. $f_{\max}$ and $l_{\max}$ can be approximately set according to actual navigation conditions.

The value of $H_n\in[0, 1]$ is the maximum of $\frac{f_n}{f_{\max\, n}}$ and $\frac{l_n}{l_{\max\, n}}$, which means that the worse the environment is, the more the value of H_n is close to 1. It is obvious that the environment influence parameter H_n makes a great impact on the risk degree $W(n)$.

3.4 *Assessment of navigators' orders*

Most shipping accidents are caused by improper orders sent by navigators. Hence, as the term for assessing the validity of orders, $M_{i,j}$ is included in the forecast model. The principle of how to get the value of $M_{i,j}$ is shown in Fig. 2.

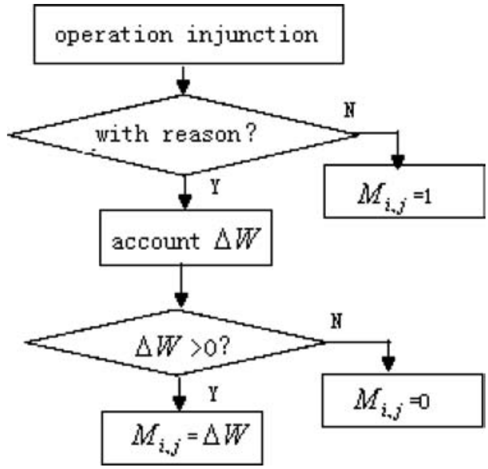

Figure 2. The choice of value $M_{i,j}$.

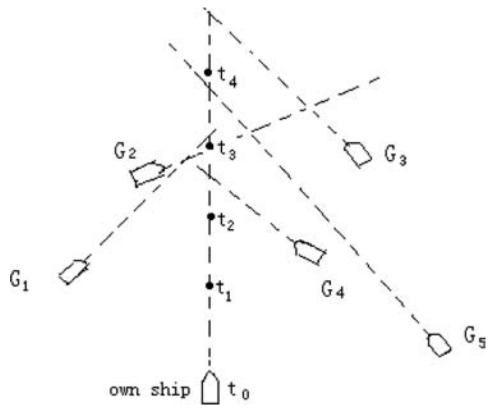

Figure 3. The navigating condition of own ship.

① Expert system of the order assessment is stored in the system. Each order sent by navigators will be analyzed whether it is reasonable according to basic operation rules and emergency operation rules. If the order violates the rules, then $M_{i,j}=1$. Fig. 2 The choice of the value $M_{i,j}$ output $W(n)$ equals to zero.

② If the order is evaluated to be valid by the expert system, the output $W(n+1)$, which is the output on the time of $n+1$ after the order is sent, should be calculated and compared with the output $W(n)$ on the time of n. The variety of $W(n)$ will be obtained through the function $\Delta W=W(n+1)-W(n)$. If ΔW is positive, it implies that the risk degree is increasing, then $M_{i,j}=\Delta W$. Otherwise, $M_{i,j}=0$.

4 PRACTICAL EXAMPLE

A practical example of the shipping accident forecast model will be illustrated as follows. A ship is navigating with the course of 60° and the velocity of 14Kn, as shown in Fig. 3.

Table 1. The moving condition of other ships in the domain of the own ship.

Object	G_1	G_2	G_3	G_4	G_5
Course (C_0)	120	136	36	24	30
Velocity (V)	16	11	10	14	12
Distance (D)	3.85	2.75	5.60	3.20	4.15
Angle of bow (Q)	335	010	035	065	121

Table 2. Collision membership function between the own ship and other ships at the moment t_0.

Object	G_1	G_2	G_3	G_4	G_5
DCPA	1.188	1.732	0.947	1.339	1.676
TCPA	0.220	0.184	0.660	0.286	0.359
u_{dT}	0.018	0.078	0	0.437	0.206
u_{tT}	0.015	0.071	0.057	0.375	0.146
U_T	0.018	0.078	0	0.437	0.206

In the definite domain, the own ship may encounter with other five ships which are marked as G_1, G_2, G_3, G_4 and G_5. The moving condition of ships is listed in Table 1.

Here, DCPA, TCPA and the collision membership function between the own ship and other ships at the moment t0 can be deduced, it is shown in Table 2, from which it can be seen that the collision risk degree between the own ship and G_4 is the highest at the moment t_0, $U_T = 0.437$. Provided that $H_n = 0$ and $M_{ij} = 0$, we have $W(n) = 0.437$. Similarly, the output $W(n)$ of the forecasting model at the time of t_1, t_2, t_3, t_4 can be calculated respectively. According to the output of the model, navigators can take proper actions to avoid shipping accidents.

5 CONCLUSIONS

A shipping accident forecast model is proposed in this paper, and the method of the predicting shipping accident is developed based on the collision risk degree, environmental influence coefficient and instruction assessment calculated in real-time. The key technology is the integration of relevant information of the shipping safety and the composition of the model. Because many complicated factors are involved in the shipping system, there are still some factors which are not considered in this paper, to name a few, evaluation rules of instructions, the reliability of the sea scanning, and the influence of visibility on sea. It is believed that with our tirelessly work and continuous development of information technology the complex shipping system can be modeled accurately to predict and avoid shipping accidents.

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1.8
Knowledge representation in a ship's navigational decision support system

Z. Pietrzykowski & J. Uriasz
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: Supporting the navigator in decision making processes may substantially contribute to the enhancement of the safety in sea transport. The navigational decision support system supplements the existing range of equipment and systems intended for sea-going ship conduct. One of the basic tasks of such systems is an analysis of a navigational situation and solving collision situations. A well functioning navigational decision support system should feature a decision-maker's (navigator's) knowledge representation. This refers to both explicit knowledge – procedural, declarative, heuristic, and tacit knowledge – empirical associations. The article presents assumptions of navigational knowledge base and its realization in the presently designed navigational decision support system.

1 NAVIGATIONAL KNOWLEDGE

1.1 *Definitions*

There is no consistent definition of both knowledge in general and navigational knowledge. It is assumed that knowledge is the total information about reality and the capability to use it.

Intuitively, knowledge is understood as the ability to behave in compliance with particular standards, norms, regulations and good sea practice.

Navigational knowledge, in turn, is to be understood as a set of data, facts, rules, procedures, strategies and theories combined with the capability of their interpretation and reasoning (Uriasz, 2008). This knowledge allows the navigator to fulfill the basic task of marine navigation, namely safe conduct of a ship from one point to another in any situation. This requirement also applies when the navigator's information is incomplete or unreliable.

1.2 *Formal requirements*

Navigational knowledge and associated competences are benchmarked and formally confirmed with IMO-approved certificates. The International Maritime Organization, aiming at the global assurance of the safety of navigation, sets forth minimum standards of professional competencies. These are contained in the STCW Convention and the relevant Code and constitute precise requirements for the competencies including the real knowledge and skills of seafarers and their task performance. The Convention in detail defines certain areas of knowledge, methods of its demonstration and assessment. The provisions of the Convention are periodically revised and updated.

The defined areas of navigator's competencies make up a formal description that contains information on the knowledge and its scope, its practical use and methods of performing certain tasks and methods of assessment.

1.3 *Scope*

Navigational knowledge can be considered from two perspectives: competencies and tasks.

The former refers to the range of knowledge for three levels as specified by the STCW Convention: management, operational and support. The Convention itself, defining minimum competence standards for performing various navigational tasks, specifies knowledge standards for seven functions. These are as follows:

- navigation,
- cargo handling and stowage,
- controlling the operation of the ship and care for persons on board),
- marine engineering,
- electrical, electronic and control engineering,
- maintenance and repair,
- radiocommunication.

The minimum scopes of knowledge are thus defined as necessary for the performance of these functions.

The latter perspective – task-based – simply results from the overall transport objective: carriage of cargo and people (voyage planning, loading, passage to the destination, unloading). To execute the above tasks one needs formalized i.e. acquired knowledge (defined, recognized facts, relationships, interrelations etc.) and, the most important, empirical association, that is knowledge acquired through practice and professional experience.

2 SYSTEM OF NAVIGATIONAL DECISION SUPPORT

2.1 *Assumptions*

The determination of navigators' competencies is strictly related with the assurance of minimum level of safety in shipping. However, satisfaction of these requirements does not eliminate the most common cause of marine accidents – human error. The construction of decision support systems broadens opportunities for the reduction of such errors. Apart from a proper situation display, the function of decision support systems is to automatically analyze and assess a situation and to work out (generate) manoeuvres recommended to the navigator for performance. One such solution comes from the Maritime University of Szczecin, where a navigational decision support system is being developed (Pietrzykowski et al. 2007).

The basic tasks for the system being designed include:

- automatic acquisition and distribution of navigational information,
- analysis of a navigational situation and avoidance of collision situations,
- interaction with the navigator.

The system should allow for the following tasks:

- signaling dangerous situations and the present level of navigational safety based on the criteria used by expert navigators,
- automatic determination of one or more manoeuvres and trajectories of ship movement in collision situations,
- possibility of explaining (justifying) of the proposed manoeuvre,
- display of a navigational situation clear for the navigator.

The navigational decision support system is intended as supplementary to the conventional shipboard equipment. Its correct operation depends on the compatibility with ship's devices and systems. The standard ship equipment includes: log, gyrocompass, radar, echosounder, ARPA (*Automatic Radar Plotting Aids*), GNSS (*Global Navigational Satellite System*), e.g. GPS (*Global Positioning System*), DGPS (*Differential Global Positioning System*), AIS – (*Automatic Identification System*), ECDIS (*Electronic Chart Display and Information System*), GMDSS – (*Global Maritime Distress and Safety System*).

There should be a possibility of adding navigational information from other sources, such as the Vessel Traffic Service (VTS).

The idea of constructing a navigational decision support system goes in line with current directions of developments in marine navigation, including e-navigation. As put in (IMO, NAV 53/13, 2007) E-navigation is the harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment". Therefore, navigational system of decision support will be a component of an e-navigation system.

2.2 *System architecture*

The system under design is one operating in real time. Its tasks include observation of the ship and the environment, registration of navigational information, its selection, retrieval, verification and processing. The navigator will be presented with the outcome of system processing – information such the identification and assessment of a navigational situation and suggested solutions (decisions) providing for safe navigation.

The system's general architecture is shown in Figure 1 (Pietrzykowski et al. 2008).

For the implementation of the tasks mentioned in section 2.1. We need to use the knowledge of expert navigators.

2.3 *Object of implementation*

The system prototype is being tested onboard the research/training vessel *Nawigator XXI*, operated by the Maritime University of Szczecin. Its basic parameters are as follows:

- length overall – 60.21 m,
- beam – 10.50 m,
- draft – 3.15 m,
- service speed – 13 knots.

The vessel has the following navigational equipment and systems:

- GPS:
  - CSI MiniMax (DGPS),
  - Koden KGP-913D,
  - Trimble NT200D (DGPS),

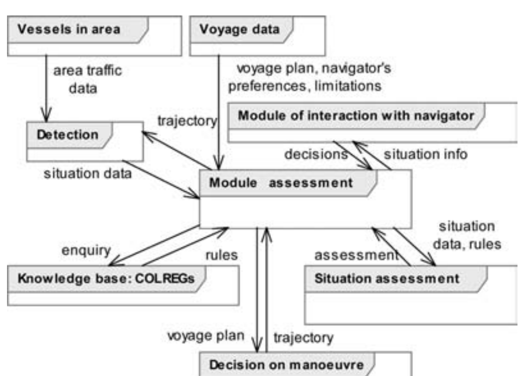

Figure 1. Architecture of the navigational support system on a sea going vessel.

– gyro: Anschutz STD22,
– AIS: Nauticast X-Pack DS,
– radar/ARPA:
  - JMA 5300,
  - Kelvin Hughes NINAS 9000,
– ECDIS: -AG Neovo,
– echosounder: -Skipper GDS 101,
– log: Sperry SRD-421 S.

The ship's equipment provides navigational data needed by the navigator to make the right decisions. The data, after integration, make up a basis for the decision support system operation, i.e. analysis and assessment of a navigational situation and the suggestion which collision avoiding manoeuvre should be performed.

3 KNOWLEDGE IN THE NAVIGATIONAL DECISION SUPPORT SYSTEM

3.1 *Types and scope of knowledge*

The requirements for the scope of navigators' knowledge comprise procedural knowledge – procedures formulated by experts – and declarative knowledge – of descriptive nature, covering sets of facts, statements and rules.

Procedural knowledge, referring to the principles of behaviour, is mainly contained in all kinds of rules and regulations.

Declarative knowledge, acquired by navigators in the course of studies, training courses and on board ship service, is related with both analysis and assessment of situations and the principles of navigator's behavior.

Both procedural and declarative knowledge is based on theories of various fields and scientific disciplines, navigation in particular.

Taking the system assumptions into account (section 2.1) as well as knowledge standards which are to be fulfilled for various functions to be performed, as defined under the STCW Convention (section 1.3), we decided to limit the knowledge implemented in the system to the function of navigation (problem 1). This knowledge includes two basic layers:

1) planning of a voyage route based on shipowner's shipping-related decisions – weather routing,
2) ship movement control accounting for the monitoring of the safety of navigation:
   – determination of safe course and speed for a present navigational situation bearing in mind the goals defined in layer 1,
   – performance of manoeuvres – rudder and engine settings according to the determined values of the course and speed.

The planning of voyage route is aimed at meeting shipowner's goals. Such planning has to take into consideration the present and forecast hydrological and meteorological conditions (access to weather information) and the knowledge in this respect. Also, the planning process is time-consuming as it requires a lot of calculations. Although it can be done onboard, the task is often ordered to specialized land-based centres. Therefore, we assumed that the planning task will be taken into consideration in further stages of development of the navigational decision support system.

Safe conduct of a vessel following the determined values of course and speed in a given navigational situation is the process that may be divided into several phases:

1) vessel detection and identification,
2) analysis and assessment of the situation,
3) defining the method of solving a collision situation – choice of a preventive manoeuvre – (manoeuvres of course and/or speed alteration),
4) determination of manoeuvre parameters, including the moment to start,
5) performance of a preventive (collision avoiding) manoeuvre,
6) monitoring of the ship conduct process.

The execution of the phases by a navigator requires that s/he has procedural and declarative knowledge as well as the knowledge resulting from the theories of scientific disciplines and fields making up the principles of navigation. The knowledge represented in the decision support system should assure that each stage of safe ship conduct is adequately performed. The implementation of this knowledge requires that its sources, methods of acquisition, representation and use are defined.

3.2 *Sources of knowledge and methods of its acquisition*

Sources of knowledge for a decision support system are scientific theories and declarative knowledge acquired by navigators during their studies, additional courses and sea service. These make up a basis for systematic principles of behaviour developed in the form of regulations, recommendations and procedures (procedural knowledge).

Procedural knowledge is particularly useful for such aim as knowledge implementation in the decision support system (Pietrzykowski, 2004). Supplemented with methods, tools and techniques offered by scientific theories covering such areas as navigation, mechanics, hydrodynamics and control, it enables making right decisions to assure the safety of navigation. However, the complex character of systems and real processes and inaccuracies or imprecisions in their description make it necessary to take into consideration the knowledge resulting from navigators' experience (declarative knowledge). It mostly has a descriptive nature and is often expressed through sets of facts (premises and implications). In this approach the knowledge comes from expert navigators.

Procedural knowledge, among others, is contained in official regulations, such as the Collision Regulations or local regulations – in many cases these are very general and their scope of interpretation can be wide indeed. A valuable source of this knowledge are handbooks on seamanship or the theory of ship handling, including information, recommendations and procedures as well as interpretation of regulations prepared on the basis of long time sea service of mariners.

Navigators' declarative knowledge is more difficult to be put into a formal framework. Its main source are facts relating to a specific issue. Such facts are obtained by a variety of research methods:

- field studies:
  - observations (passive)
  - experiments (active)
- model-based research:
  - physical (based on material models),
  - mathematical.

Model-based research is particularly useful when combined with computer-aided simulation methods. The advantage of such research is due to difficulties of real field studies: high costs, limited possibility of registration of varied situations, while in the case of new projects there is no such possibility at all.

In knowledge acquisition, expert studies are an important option. Expert studies can be performed in the form of questionnaires or simulations with experts as participants.

The above mentioned methods have to be supplemented with analytical, statistical and artificial intelligence methods that are needed to identify relationships and dependencies in sets of facts collected by the methods in question. For this reason, artificial intelligence methods, tools and techniques are of particular interest: machine learning, artificial neural networks, fuzzy systems or evolutionary algorithms. These techniques allows to work out a representation of knowledge in the decision support system: directly (e.g. machine learning, artificial neural networks) or indirectly (fuzzy systems, evolutionary algorithms).

Various types of knowledge and the complexity of problems connected with its acquisition make it necessary to use a group or groups of methods.

The following sources and/or methods have been defined for each phase of safe vessel conduct (see section 3.2):

1) detection and identification of a vessel (including parameters of its movement):
   - analytical methods (verification, selection and integration of navigational data),
   - artificial intelligence methods (estimation of the state vector of another vessel)
2) situation analysis and assessment:
   - analytical methods (algorithmization of COLREGs)
   - analytical methods – closest point of approach (CPA) and time to CPA
   - expert methods – questionnaires, and statistical methods (situation assessment criteria)
   - simulation methods with experts' participation and statistical methods (situation assessment criteria)
3) pointing out the method for collision situation avoidance – choice of a preventive manoeuvre;
   - analytical methods (algorithmization of COLREGs, classical optimization algorithms)
   - artificial intelligence methods (fuzzy systems, genetic algorithms);
4) determination of manoeuvre parameters
   - analytical methods (classical computational algorithms, including optimization algorithms)
   - artificial intelligence methods (fuzzy systems, genetic algorithms)
5) performance of a preventive (anti-collision) manoeuvre
   - analytical methods (classical control algorithms)
   - artificial intelligence methods (fuzzy systems)
6) monitoring of ship conduct process:
   - analytical methods (prediction of vessel movement).

The use of the above methods allows to acquire and implement (representation and use) of navigators' knowledge in the decision support system for safe vessel conduct.

4 REPRESENTATION AND USE OF KNOWLEDGE IN THE DECISION SUPPORT SYSTEM

4.1 *Knowledge representation*

The acquired knowledge should be recorded in forms suitable to its purpose or method of utilization. The following methods of representation can be applied:

Database structures. Databases allow to gather sets of data and to record them in a specified manner for the adopted model. They enable efficient edition of data, their updating, archiving and further processing. Database applications in navigation get increasingly wider as information technologies are constantly being advanced. One such example is VDR, voyage data recording. Various facts of a given voyage may be used in the process of knowledge supplementing (situations and manoeuvres performed by navigators). Another example is the conception of WEND – Worldwide Electronic Navigational Chart Database (Hecht, 2007).

The electronic navigational chart represents a basic source of knowledge on a given water area and essentially complements the navigator's knowledge. Its database form enables a choice of the appropriate layers of vector data for the execution of navigational tasks (see 3.1)

Rules and decision trees. Rules represent the knowledge defining the conditions for assigning registered facts to distinguished classes: they define premises, implications and conclusions. Decision trees execute a similar task. They enable solving a classification problem for two or more classes.

Both rules and decision trees constitute such a form of knowledge that is well implemented in expert systems. Decision trees allow to describe the decision process – reasoning.

Decision tables. Another useful form of recording knowledge is its representation as logical decision tables. The table contains a description of a decision situation (DS), which is defined as a set of ordered threes:

$$(U_{dz}, H, f_u) \tag{1}$$

where,
U_{dz} – set of possible actions,
H – set of possible results of actions,
f_u – utility function defined on the Cartesian product.

$$U_{dz} \times H$$

In marine navigation it is justified to use this method of knowledge representation, as it enables not only foreseeing the results of a particular decision but also, more importantly, adjusting the right actions to the planned result.

Neural networks. These are mathematical structures able to process signals. Their operation is based on the reproduction of processes taking place in brains of living organisms. In the construction of a neural network, one has to define the network structure, then to carry out the learning process resulting in the correct operation of the network, with a maximum adopted error. Neural networks find applications in approximation problems, image recognition, forecasts, selection, optimization etc.

Algorithms. An algorithm is a convenient and clear-cut method of knowledge recording. In fact, it is a detailed procedure for solving a problem. Recurrent algorithms in particular are very close to natural behaviour of the human being by allowing to present part of a problem instead of the whole. When in operation, the algorithm refers to itself until a solution to the problem is reached. Most problems in navigation are solved in a recurrent method, e.g. voyage planning and passage, planning and performance of a SAR operation, vessel detection and identification. Typical computational algorithms, including optimization algorithms, are an important group. They represent theoretical knowledge that allows to solve specific computation problems, e.g. determination of ships encounter parameters or parameters for performing a manoeuvre.

4.2 *Utilization of knowledge in the decision support system*

The system supporting navigator's decisions has to have the right scope of knowledge indispensable for its functioning. The knowledge recorded in the system will be represented in forms mentioned in section 4.1; these are in particular:

- database structures – in this form the system includes navigational cartographic information. The information, satisfying IHO standards, will make up a basis for presenting current navigational information. All manoeuvre recommendations will account for the vicinity of dangers to navigation.
- rules and decision trees – the navigator keeping a navigational watch does a number of actions: carries out observations, assesses present navigational situations, plans and performs manoeuvres. During these actions the navigator has to classify surrounding conditions and encounter situations by assigning them to various groups, which imply the application of different rules provided by internationally recognized collision regulations (COLREGs). The classification rules – principles used for this purpose in decision support systems may provide a relevant classification as well as contribute to the development of comparable criteria for classification used by navigators. This refers to special cases when the classification is based on incomplete or inaccurate information.
- decision tables – such record of knowledge will contain information on manoeuvres – their parameters, starting moment and effects. The navigator will be left to decide on which manoeuvre to choose (its type and parameters).
- neural network – this will be used for the assessment of navigational safety in an encounter with other vessels; such assessment will take into account the parameters of vessels encountered. It allows to determine an area around the ship that should be maintained clear of other objects – ship domain (Pietrzykowski & Uriasz, 2009). The network will also be used for the determination of collision avoiding manoeuvres. As a universal approximating device, it will also be utilized in the process of state vector estimation of other vessels.
- algorithms – in the decision support system, among others, the interpretation of COLREGs is presented in the form of an algorithm. Based on recurrent algorithms, such operations as vessel acquisition or information decoding is executed. Complex computational algorithms have been used in the integration of navigational data from various shipboard devices and systems. Standard computational algorithms as well as complex optimization algorithms are used for selecting manoeuvres and their parameters.

5 CONCLUSIONS

As the types and scopes of navigators' knowledge and the methods of its acquisition and representation are varied, different forms were used for knowledge implementation and utilization in the decision support system.

The created knowledge base has a distributed nature. It includes the knowledge used in each stage of the process of navigation, or ship conduct.

The decentralized structure of the knowledge base make possible both supplements in terms of scope and representation forms. It can be complemented with navigators' knowledge in the area of voyage planning, and subsequently, it may cover the other six functions (apart from navigation) specified in STCW competence standards for enhanced performance of specific tasks.

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Chapter 2. Manouvering and ship-handling simulation

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2.1
Manoeuvring simulation on the bridge for predicting motion of real ships and as training tool in ship handling simulators

K. Benedict, M. Kirchhoff, M. Gluch & S. Fischer
Hochschule Wismar University of Technology, Warnemünde, Germany

M. Baldauf
World Maritime University, Malmö, Sweden

ABSTRACT: International sea transport has growing rapidly during the period of the last decade. Ships became larger and wider and its container capacity is still increasing to 12.000 TEU and even more. To navigate such vessels safely from port to port and specifically within the ports more and more enhanced computer-based systems are installed on the ships navigational bridges. Prediction tools are very helpful and already in use on ships for a long time. However, the simplification of existing predictions allows restricted use only and do not include the immediate response on changes of rudder and engine. Within this paper investigations into the feasibility and user acceptance of newly developed layout of navigation display will be introduced and selected results of simulation studies testing the influence on manoeuvre performance dependent on different kind of prediction functions will be discussed. Examples will be given for results from test trials in the full mission ship handling simulator of the Maritime Simulation Centre Warnemunde and a concept for the application of the developed tools for purposes of collision avoidance is described.

1 INTRODUCTION

International sea transport has growing rapidly during the period of the last decade. Ships became larger and wider and its container capacity is still increasing to 12.000 TEU and even more. To navigate such vessels safely from port to port and specifically within the ports from and to the dedicated berths more and more enhanced computer-based systems are installed on the ships navigational bridge to support the pilot, the master and his navigating officers as well.

Investigations are ongoing to integrate features for new manoeuvring and steering equipment such as azimuth propellers or waterjets and in parallel to enhance the predictions of the complex own ship motions taking into account the use of the controls in time.

Prediction tools are very helpful and are already in use on ships for a long time, beginning with trial modes in ARPA radars up to curved headline overlay in ECDIS. However, the simplification of these predictions allows restricted use only based either on estimated future courses & tracks or on the simple integration of the current ship motion not including the immediate response on changes of rudder and engine.

New concepts for on board displays and simulation tools were developed in research projects funded by the German Federal Ministry of Education and Research together with partners from manufacturers like SAM Electronics Hamburg and INTERSCHALT/AVECS.

A prediction tool was developed to simulate the ships motion with complex dynamic models in fast time and to display the ships track immediately for the intended or actual rudder or engine manoeuvre. These simulations are based on input from the ships actual sensors via the Voyage Data Recorder and furthermore from diagnosis tools analysing the status of the manoeuvring facilities and providing information in case of failures, e.g. reduced engine power or larger rudder response time due to malfunctions of the equipment.

This tool can be used both for real ships operation on board but also for the effective training in simulators because of its unique advantage that the consequences of manoeuvring commands can be seen immediately before the ship has even changed her motion.

Within this paper investigations into the feasibility and user acceptance of the new layout of navigation display will be introduced and selected results of simulation studies testing the influence on manoeuvre performance dependent on different kind of prediction functions will be discussed. Examples will be given for results from test trials in the full mission ship handling simulator of the Maritime Simulation Centre Warnemunde.

2 STATE OF THE ART AND NEW APPROACH

The role of computer based simulation is increasing on the ships bridge, especially for manoeuvre planning and for collision avoidance. Prediction tools are very helpful and already in use on ships for a long time. Well known is the so called Trial Manoeuvre mode in ARPA radars to be used in order to analyse future encounter situation for selected relevant course and speed alternatives to deck potential collision avoidance strategies.

With the emerging Electronics Chart and Information Systems ECDIS new tools were introduced for supporting voyage planning by means of manoeuvring characteristics. For controlling the ship on her route the future track of the ship was shown as a so called "curved headline" overlay in ECDIS.

However, theses prediction are very simple only based either on new constant course and speed values as in the ARPA trial function or on estimated future courses & tracks based on the simple integration of the current ship motion parameters as rate of turn and speed components to be considered as constant.

The simplification of these predictions allows restricted use only. That is why new concepts for on board displays and simulation tools were developed using an innovative approach which includes the immediate response on changes of rudder and engine commands for the display of the future track.

This approach was investigated in research projects, dedicated on the one hand to the further development of user interfaces on ships navigational bridges and to investigations into potential improvements for manoeuvring assistance on the other hand.

A prediction tool was developed to simulate the ships motion with complex dynamic models in fast time and to display the ships track immediately for the intended or actual rudder or engine manoeuvre (Benedict, Baldauf et al 2007). Generally there are two areas of application of such a prediction tool. It can be seen both as training tool for ship manoeuvres and to be used as assistance tool on board vessels:

- **Training Tool**: The prediction of ships motion as an immediate response could be an excellent method to demonstrate the results of changes or alternatives of using manoeuvring control devices as for instance propellers, rudders or thrusters. This is of increasing importance specifically for the growing complexity of manoeuvring control systems starting from simple one-propeller and middle rudder, via twin propellers with double rudder up to new azimuth propellers which can be turned by 360° (there are ships with even four of these sophisticated thrusters).
- **Assistance Tool**: Predictions as elements of on board displays can be used as in the loop control elements to steer the ship manually but supported by the future track or speed indication in the ECDIS interface.

One crucial problem for the prediction is the accuracy of the simulation. In the mentioned projects a very sophisticated approach was used to represent the ships' dynamic by very extensive equations very similar to those used in Full Mission ship handling simulators. The parameters of the equation of motion will be

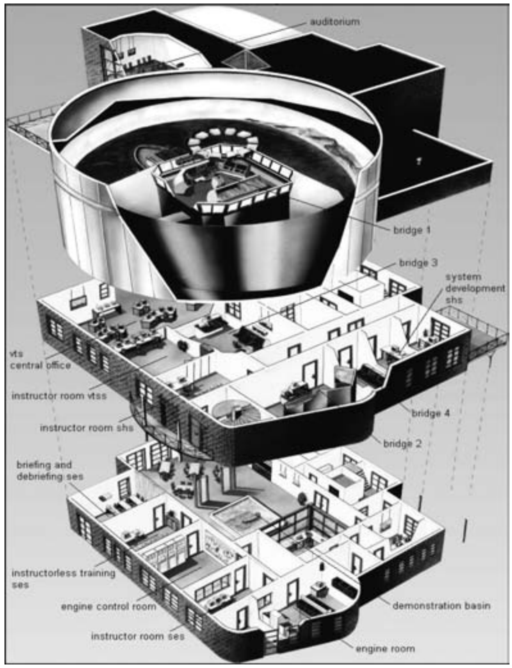

Figure 1. Maritime Simulation Centre at Warnemuende (MSCW) which comprises three interfaced simulator segments for ship handling, ship engine and VTS.

estimated by an extra fast time simulation program and a data analyser already used for tuning of the hydrodynamic models in the ship handling simulator. These methods will be described in the following chapters and examples will be given for results from test trials in the full mission ship handling simulator of the Maritime Simulation Centre Warnemuende upgraded in 2007/2008.

This Simulation Centre accommodates six simulators embracing a common network and comprised of four ship-handling bridge systems with differing levels of equipment, a ship's engine system and a VTS simulation facility.

The interaction of many of the single simulators is one of the unique features of the MSCW: they can be interfaced to form a big scenario comprising all simulators and connecting e.g. the big bridge 1 with the full mission engine simulator. (Benedict 2000).

3 APPROACH FOR PREDICTION TOOL

3.1 *Ship dynamic model and technological setup*

The following equation of motion was used as math model for the ships dynamic:

$$X = m(\dot{u} - rv - x_G r^2)$$

$$Y = m(\dot{v} + ru + x_G \dot{r})$$

$$N = I_z \dot{r} + m x_G (\dot{v} + ru)$$

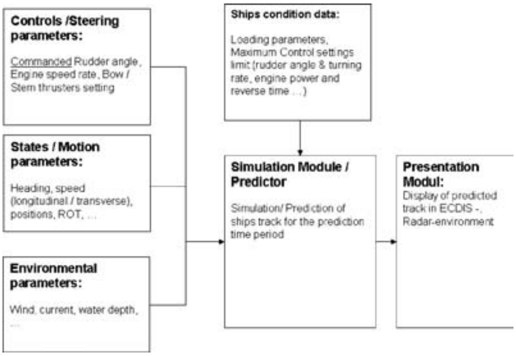

Figure 2. In-/Output concept for prediction process and data flow.

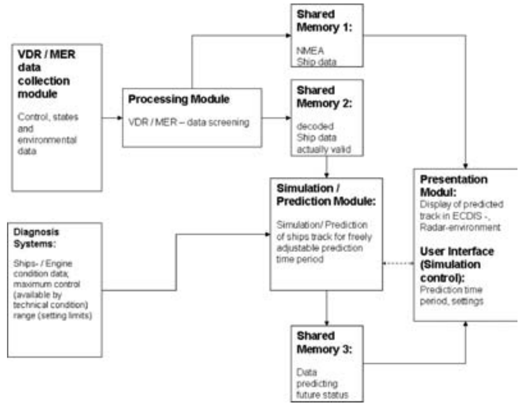

Figure 3. Modules & data sources and sinks.

On the right side are the effects of inertia where u and v represent the speed components in longitudinal and transverse direction x and y, r is the rate of turn of the ship. The ships mass is m and x_G is the distance of centre of gravity from the origin of the co-ordinate system, I_z is the moment of inertia around the z-axis.

The ships hull forces X and Y as well as the yawing moment N around the z-axis are on the left side. Their dimensionless coefficients are normally represented by polynomials based on dimensionless parameters, for instance in the equation for transverse force Y and yaw moment N given as the sum of terms with linear components Nr, Nv, Yr and Yv and additional non-linear terms. Other forces as for instance rudder forces and wind forces are expressed as look up tables. There are additional equations for the engine model, where are also look up tables to represent automation systems characteristics. The solution of this set of differential equations is calculated every second; some internal calculations are even done with higher frequency.

The Input output relations are shown in Figure 2. The inputs consist of controls, the states and the data for the environmental conditions in the three blocks on the left side. The core module Simulation/Prediction is in the centre of the figure. Additionally there is an input of the Ships condition parameters. They are normally fixed but in case of malfunctions they might change, e.g. reducing the rudder turning rate or maximum angle. The results from the Simulation block are transferred to be displayed in ECDIS or Radar.

In Figure 3 the more technological setup of the structure of modules is described. A commercial IMO-proven Voyage Data Recorder (VDR) plays the role of data collector for the controls, states and environmental parameters measured by the ship sensors.

After pre-processing the data will be stored in Shared Memory 1, together with the condition parameters which will be provided by a diagnosis system. This system continuously checks the ships and engine conditions. From this memory the data are available for other modules:

– The Simulation Prediction Module uses the data from Shared Memory 1 to predict the ships track and speed for a certain time period. The results are sent to Shared Memory 2.
– The Presentation Module uses the data both to display the actual position and from Shared Memory 2 to display the future track.
– The Prediction parameters are controlled by an user interface integrated in the Presentation module with regard to predicting cycle and length of track.

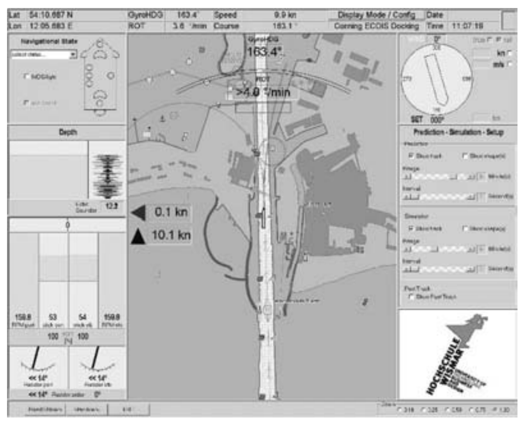

Figure 4. Layout concept for manoeuvring prediction in ECDIS.

3.2 *Presentation of dynamic predictions in ECDIS environment*

For a compact presentation of information to the captain, pilot and responsible navigating officer respectively a new layout of a conning display was designed and implemented into the equipment installed on an integrated navigation system. The display layout contains an overlay of ECDIS and CONNING information together with the prediction (figure 4).

In the centre the ECDIS information in Head up Mode together with motion parameter for longitudinal speed (10.1.kn and transverse speed (0.1 kn) as well as a circle segment with the rate of turn to STB ((4.0°/min) is shown. The ships position is displayed in the centre

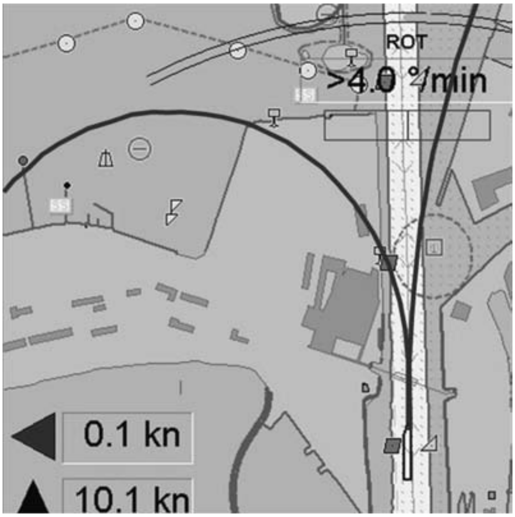

Figure 5. Comparison of methods based on different tracks.

of the ECDIS as ships contour where the track prediction can be indicated as curved track or as chain of contours for the selected prediction time. The prediction parameters as range or interval of presentation can be set in the control window at the right side.

The predicted track for the simplified prediction is shown as red curve (here shown in black to starboard): According to the actual rate of turn to starboard the conventionally predicted track is presented as a circle segment to the right side as track for the time range of 5 min with a speed of 10.1 kn.

The dynamic prediction with the full simulation model is shown as blue curve (here shown in black to port). This dynamic prediction reflects the setting of rudder and propeller parameters shown in the left bottom window: The two rudders of the ferry used in this example are set to 14° Port and the Engine Order Telegraph for the two controllable pitch propellers are set to 100% representing 159.8 rpm of the propeller. The actual pitch status is 53 and 54 respectively. This interface allows for a presentation of dynamic predictions of steering and stopping characteristics as an immediate response according to the current steering handle or engine order telegraph position.

3.3 *Investigations into the effects of predictions on ship handling*

For the purpose of testing the potential effects of such enhanced prediction tool it was implemented in the INS equipment of the large full mission simulator bridge of the Ship handling simulator of MSCW.

For trials to test the effects of such a tool on the navigators behaviour a sample of a PanMax container vessel with Loa = 294m, Boa = 32,2 m, Draft = 12 m and a Displacement of 74.000 t is used in the simulation experiment. The container vessel is equipped with one fixed propeller and one balanced rudder blade. Additionally one bow thrusters is available for manoeuvring the ship.

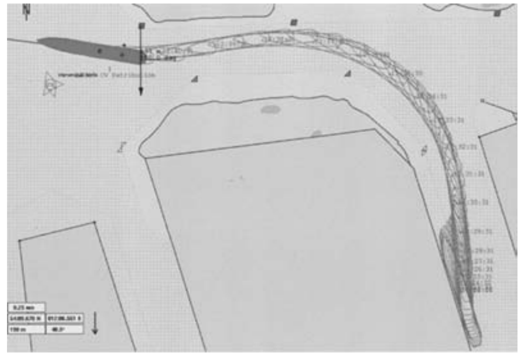

Figure 6. Sample of a result from experimental trial to investigate effects of predictions tool.

A first basic test scenario was developed and implemented. The task is to steer a vessel from a berth into a fairway to leave a harbour area. The scenario is used for trials with participants who are not familiar with the selected ship. The task to be performed is to safely manoeuvre the ship into the fairway. Each participant started with a trial to become familiar with the ships behaviour and without using the prediction tool. The second run of the test contains the same task but were performed in another area of the port. An example of a trial using the prediction tool is given in the following figure.

After the first series of simulation runs there are already some tendencies regarding the effects that can clearly be identified.

- There are successful manoeuvres, when the predictor was used; even if the test person has no experiences for the specific ship and the area.
- The execution time for the manoeuvre is smaller when the predictor is used.
- The number of orders (for engine, thrusters and rudder) decreases with the use of the predictor.

To proof these tendencies the trials will be continued with cadets during the next semesters. Then more detailed investigations with more detailed statistical analysis will be performed.

4 APPLICATION OF THE PREDICTION MODULES FOR ON BOARD COLLISION AVOIDANCE

The prediction algorithm and the technical setup is planned to support pilots, captains and navigating officers when manoeuvring a ship in narrow waters, moreover it also may be applied for the improvement of the on board collision avoidance process. There are ongoing investigations to enhance the existing collision warnings by using predicted manoeuvring characteristic data for adaptation of alarm thresholds in contrary to conventional CPA/TCPA calculations and fixed limit values to be applied to every encounter situation without any distinction of the prevailing circumstances of the encounters.

Core element of this new approach is the risk model for situation assessment (Hilgert, Baldauf 1996) differing between the three types of encounter situations and additionally taking into account the two conditions of visibility as laid down in the International Rules for Preventing Collisions at Sea as well. Furthermore the concept is also applied to the new IMO's definition given in the new performance standards for INS (IMO, (2007) and allows for introducing situation dependent collision alert categories "Caution", "Warning" and "Alarm" as well. Cautions and warnings may be switched off by the operator, but alarms may not.

For self adaptation of thresholds different CPA limits are foreseen, which will be set automatically according to the hydrodynamic safe passing distance related to the dimensions of the involved ships, the actual sea area and visibility conditions as well.

As suggestion for initial basic values CPA limits were determined by detailed field study. To ensure a wide range of user acceptance one emphasis was laid on the navigators' behaviour and taken into account. From the point of view of well experienced navigators it is rather more practical to determine the safe passing distance with respect to usual data. Under pragmatic aspects and according to the investigations performed it can be assumed that the nominal safe passing distance have to be in relation to the ship's length of the largest vessel L_{max} involved in an encounter situation (L_{max} should not be less than 1 cbl). Taking into account the different types of encounter situations as defined in the COLREGs a factor "f_x" is necessary which depends on the kind of situation "x" and the can be determined by

$$\text{Safe Passing Distance (nominal)} = f_x \cdot L_{max}).$$

The values, given in Table 1, are derived from several investigations (see i.a. Baldauf (2004)) and are suggested for the four main types of encounter situations.

These values were proved by simulation studies and are valid under the conditions "open sea" for good (column 2) and restricted visibility (column 3).

Table 1. Recommendation for basic values to calculate situation dependent threshold.

Kind of encounter situation	f_x (good visibility)	f_x (restricted visibility)
Head-on situation Meeting port/port-side	2.5	5
Overtaking	2.5	5
Head-on situation Meeting stb/stb	5	10
Crossing situation	5	10

These values have to be applied to the actual encounter situations.

With respect to the technical setup for predictions described above manoeuvring data, especially the response time for a potential course change of 90°, may be taken from extracted processed VDR recordings and used for automatic adaptation of the TCPA related limits of the dangerous target alarms, either by taking them directly from a database or by calculations using the fast time simulation algorithms. The response time for turning manoeuvre is a fundamental value to avoid a collision. Such response times are only available to captains on board for some standard manoeuvres under selected environmental and loading conditions as well and they are usually neither exactly known nor applicable to the prevailing circumstances of a concrete dangerous situation to be solved. A sample of a standard set of response times for a usual sized 5.000 TEUs container vessel is given in Table 2.

As stated before, when applying the drafted concept for situation dependent alarm thresholds those values should be determined by means of the manoeuvring prediction module. The principal application's structure and the relevant data flows are given in the figure below.

Table 2. Response times for turning manoeuvre depending on own ships speed and rudder angles.

Own speed (kt)	Rudder angle (°)	Time for course alteration of 90° $t_{90°}$ (min)	Covered distance $t_{90°}$ d_{OS} (nm)
24	Hard a-starboard	2:25 min	0,97
24	Starboard 15	3:51 min	1,54
22	Starboard 20	3:24 min	1,25
22	Starboard 15	4:10 min	1,53

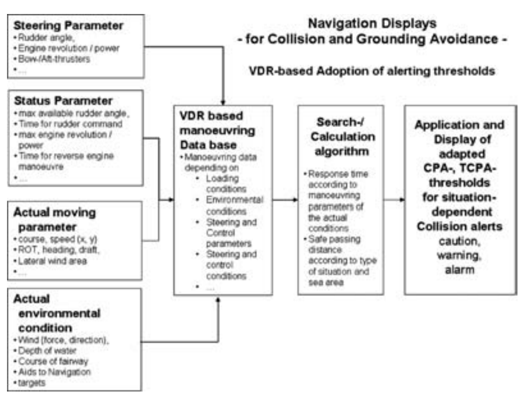

Figure 7. Principal application structure and data flow for self-adaptation of thresholds for collision alerts.

First studies applying the situation dependent thresholds for detection of dangerous encounter situations in overall traffic scenarios in sea areas off the coast monitored by VTS resulted in a reduction of the number of collision alerts by 40%.

5 SUMMARY

A prototype software module for an On-line Manoeuvring Assistance is developed based on a prediction tool using advanced simulation technology on board of ships. The results of rudder and engine control changes will be immediately displayed in an Electronic chart environment to be used for manual correcting steering actions. The system was tested using the excellent resources for research and development of the Maritime Simulation Centre Warnemunde and can be used also as a training tool in student courses. During test trials several manoeuvring situations were managed with an increased performance when using the prediction tool. A concept for the application of the tools for purposes of collision avoidance is developed in order to reduce the number of alarms.

ACKNOWLEDGEMENTS

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2.2 CFD based hull hydrodynamic forces for simulation of ship manoeuvres

T. Tabaczek, T. Górnicz & J. Kulczyk
Wrocław University of Technology, Wrocław, Poland

ABSTRACT: There have been developed numerous mathematical models describing the motion of a ship. In opinion of present authors the CFD is mature enough to determine with confidence the hydrodynamic characteristics necessary to simulate ship manoeuvres. In this paper the authors present the attempt to determine the hull hydrodynamic forces using the results of CFD computations of ship flow. Results show qualitative agreement with reference data and reveal shortcomings due to simplifying assumptions applied in CFD computations.

1 INTRODUCTION

During the process of designing a new ship the designer has to answer a lot of questions. Some of them refer to the manoeuvrability of a ship. Moreover, the IMO regulations define precisely the minimum manoeuvring requirements. The possibility to determine the manoeuvring properties in early stage of design results in significant reduction of cost and time. There have been developed numerous mathematical models describing a motion of a ship. The authors of those methods usually report common problems like poor accuracy, limited range of application, or need of model tests to determine characteristics and coefficients. Recent advances in IT and CFD are promising in solving problems referring to the need of model tests. In the opinion of the present authors the CFD is mature enough to determine most of hydrodynamic characteristics necessary to simulate ship manoeuvres. The characteristics of hull, propeller and rudder and interactions between hull, propeller and rudder can be determined separately with confidence. In this paper the authors present the attempt to determine the hull hydrodynamic forces using the results of CFD computations of ship flow.

2 EQUATIONS OF SHIP MOTION

Usually the equations of ship motion are written in the co-ordinate system with the origin at the centre of gravity of a ship. The left-hand sides of equations describe the dynamics of rigid body, and the right hand sides represent the external forces:

$$\begin{aligned} m\dot{u} - mvr &= X \\ m\dot{v} + mur &= Y \\ I_{zz}\dot{r} &= N \end{aligned} \tag{1}$$

m denotes the mass of a ship, u, v, r – forward speed, transverse speed and yaw rate, $\dot{u}$, $\dot{v}$ and $\dot{r}$ – accelerations in respective directions, I_{zz} – the moment of inertia of a ship, X, Y and N – the external forces: surge force, sway force and yaw moment, measured at ship's centre of gravity.

The same equations can be written in a co-ordinate system with the origin at midship:

$$\begin{aligned} m(\dot{u} - vr - x_G r^2) &= X \\ m(\dot{v} + x_G\dot{r} + ur) &= Y \\ I_{zz}\dot{r} + mx_G(\dot{v} + ur) &= N \end{aligned} \tag{2}$$

In this case u, v, r, X, Y, N denote rates and forces measured at midship, and x_G – the distance from the midship to the centre of gravity.

Sometimes it is convenient to solve equations written in co-ordinate system with origin at the centre of gravity when forces are determined at midship:

$$\begin{aligned} m\dot{u} - mvr &= X \\ m\dot{v} + mur &= Y \\ I_{zz}\dot{r} &= N - x_G Y \end{aligned} \tag{3}$$

Equations (3) are also used in the following for simulation of ship motion.

3 EXTERNAL FORCES

In order to verify the idea of determination of hydrodynamic forces using CFD the present authors chosen the modular model of MMG to represent the external forces acting on manoeuvring ship:

$$\begin{aligned} X &= X_H + X_P + X_R \\ Y &= Y_H + Y_R \\ N &= N_H + N_R \end{aligned} \tag{4}$$

The subscripts "H" "P" and "R" denote the hull hydrodynamic forces and forces from propeller and rudder respectively. This modular model is suitable for testing the individual mathematical models one by one.

3.1 *Hull hydrodynamic forces*

The mathematical model described in [1] was used to represent hull hydrodynamic forces for its simplicity and availability of reference data. Model is based on the quasi-steady approach and forces depend only on rates and accelerations:

$$X'_H = X'_0 + X'_{vv}v'^2 + (X'_{vr} - m'_y)v'r' + X'_{rr}r'^2 + X'_{vvvv}v'^4$$

$$Y'_H = Y'_v v + (Y'_r - m'_x)r + Y'_{vvv}v'^3 + Y'_{vvr}v'^2 r + Y'_{vrr}v'r'^2 + Y'_{rrr}r'^3$$

$$N'_H = N'_v v' + N'_r r' + N'_{vvv}v'^3 + N'_{vvr}v'^2 r' + N'_{vrr}v'r'^2 + N'_{rrr}r'^3$$

u', v', r' denote the non-dimensional rates, $X_0 = -R_T(u)$ – ship resistance in considered co-ordinates, and $X'_{vv}, X'_{vr}, \ldots, Y'_v, Y'_r, \ldots, N'_v, N'_r, \ldots$ – hydrodynamic coefficients.

The non-dimensional forms of forces are defined as follows:

$$X = X' \cdot \frac{\rho}{2} \cdot L^2 \cdot U^2$$

$$Y = Y' \cdot \frac{\rho}{2} \cdot L^2 \cdot U^2$$

$$N = N' \cdot \frac{\rho}{2} \cdot L^3 \cdot U^2$$

3.2 *Propeller force*

The model described in [2] was adopted to represent the longitudinal force generated by propeller, including the effects of propeller-hull interaction:

$$X_P = C_{tP}(1 - t_{p0})n^2 D_P^4 K_T(J_P) \qquad (5)$$

$$K_T(J_P) = C_1 + C_2 \cdot J_P + C_3 \cdot J_P^2$$

$$J_P = U \cos\beta \frac{1 - w_P}{nD_P}$$

$$w_P = w_{P0} \cdot \exp(-4.0\beta'^2)$$

$$\beta' = \beta - x'_P \cdot r'$$

t_{P0} denotes thrust deduction factor in straight ahead ship motion, n – rotational speed of propeller, D_P – propeller diameter, K_T – thrust coefficient, J_P – advance coefficient, C_1, C_2, C_3 – coefficients for evaluation of K_T from open water characteristics, U – ship speed, β – drift angle, w_{P0} – effective wake fraction in straight ahead ship motion, x'_P – non-dimensional x-ordinate of propeller.

3.3 *Rudder forces*

Forces from the rudder, including the interaction between hull, propeller and rudder, are calculated using the mathematical model described in [2] for rectangular spade rudder:

$$X'_R = -(1 - t_R)F'_N \sin\delta$$

$$Y'_R = -(1 + a_H)F'_N \cos\delta \qquad (6)$$

$$N'_R = -(x'_R + a_H \cdot x'_H)F'_N \sin\delta$$

$$\eta = \frac{D_P}{h_R}$$

$$K = 0.6\frac{1 - w_P}{1 - w_R}$$

$$s = 1 - (1 - w_P)U\frac{\cos\beta}{nP}$$

$$w_R = w_{R0}\frac{w_P}{w_{P0}}$$

$$\alpha_R = \delta - \gamma \cdot \beta'_R$$

$$\beta'_R = \beta - 2x'_R \cdot r'$$

$$U_R^2 = (1 - w_R)^2(1 + C \cdot g(s))$$

$$x'_R = \frac{x_R}{L}$$

$$x'_H = \frac{x_H}{L}$$

$$F'_N = \left(\frac{A_R}{L \cdot d}\right)C_N U_R^2 \sin\alpha_R$$

$$C_N = \frac{6.13 \cdot K_R}{K_R + 2.25}$$

$$g(s) = \eta K\frac{(2 - (2 - K) \cdot s)s}{(1 - s)^2}$$

t_R – denotes the coefficient for additional drag, F_N – normal force acting on rudder, δ – rudder angle (positive to starboard), a_H – ratio of additional lateral force, x'_R – non-dimensional x-ordinate of application point of F_N, x'_H – non-dimensional x-ordinate of application point of additional lateral force, h_R – height of rudder, s – propeller slip coefficient, P – propeller pitch, w_{R0} – effective wake fraction at location of rudder, in straight ahead ship motion, α_R – effective rudder inflow angle, γ – flow straightening coefficient, U_R – effective rudder inflow velocity, A_R – rudder area, K_R – aspect ratio of rudder.

4 HYDRODYNAMIC COEFFICIENTS

The clue of the present paper is the approximation of hull hydrodynamic forces using the results of CFD

Table 1. Data for simulation of motion of the *Esso Osaka* model ship.

L_{PP}	6.0 m
B	0.978 m
T	0.402 m
C_B	0.83
x_G	0.190 m
$m' = m/½\rho L^3$	0.01813
$I'_{zz} = I_{zz}/½\rho L^5$	0.00110
$m'_x = m_x/½\rho L^3$	0.00138
m'_x (computed)	0.00133
$m'_y = m_y/½\rho L^3$	0.01580
m'_y (computed)	0.01703
$J'_{zz} = J_{zz}/½\rho L^5$	0.00069
D_P	0.168 m
P/D_P	0.715
t_{P0}	0.27
w_{P0}	0.365
A_R	0.0408 m^2
h_R	0.256 m
K_R	2.49
U_0	0.699 m/s

computations. To this end a series of ship flow computations was carried out for a couple of combinations of drift angle and yaw rate. The scope of drift angle and yaw rate was predetermined based on results of free running model tests of basic manoeuvres, i.e. the turning manoeuvre and the 15/15 deg zig-zag manoeuvre [1]. It was estimated that drift angle varies in the range $-10 < \beta < 20$ deg and yaw rate in the range $0 < r' < 1.0$.

Computations of ship flow were carried out with the assumption of low Froude number (negligible heel and effect of free surface). The commercial Fluent software was used to compute single phase, turbulent steady flow in moving reference frame.

Same assumptions were applied when computing the flow around the accelerating ship, in order to determine the components of added mass: m_x and m_y. In this case the accelerated flow with constant acceleration was computed around ship in rest.

Computed forces, moment and components of added mass were subsequently used to determine all hydrodynamic coefficients in the mathematical model (5). The coefficients were estimated using standard statistics procedure of fitting the user defined function to the set of data.

Reported computations and simulations described in next section were carried out for the *Esso Osaka* model ship of length $L_{PP} = 6.0$ m. Hydrodynamic forces approximated using coefficients given in [1] and coefficients based on CFD computations are compared in Fig.1. If one takes the hydrodynamic forces approximated using coefficients from [1] as reference, surge force X'_H seams to be predicted satisfactory. Sway force Y'_H is predicted well except for drift angles above 10 deg. Yaw moment N'_H is overpredicted at drift angles above 10 deg and at high yaw rate $r' > 0.4$. The effect of differences in hydrodynamic forces on the manoeuvring performance of model ship is shown in the next section.

5 SIMULATION OF STANDARD MANOEUVRES

The turning manoeuvre and the 10/10 deg zig-zag manoeuvre of model ship were simulated using equations (3), nodular model (4) of external forces, and mathematical models of hull, propeller and rudder forces described in previous sections. Data for simulation collected from [3] and [4] are listed in table 1. Model ship resistance was estimated according to the idea of form factor:

$$C_{TM} = (1+k)C_{F0M} + C_{RM}$$

There were applied the ITTC-57 model-ship correlation line to evaluate frictional resistance C_{F0M}, the assumption of low Froude number (negligible wave resistance $C_{RM} = 0$), and the form factor $k = 0.27$. Open water propeller characteristics $K_T(J)$ was approximated using the characteristics of corresponding propeller from B-Wageningen screw series.

The differential equations of motion (3) were solved using 4-th order Runge-Kutta method with adaptive time step. However, the examinations shown that this equation can be solved even precisely with simpler methods but with the time step restriction.

The results of simulation of turning manoeuvre with $\delta = 35$ deg are shown in figures 2 and the results of 10/10 deg zig-zag manoeuvre are shown in figure 3. The differences in estimation of hydrodynamic forces seen in figure 1 are reflected also in results of both simulations.

6 CONCLUSIONS

The authors used the results of CFD computations of ship flow to approximate hydrodynamic forces and moment for simulation of ship manoeuvres. The comparison of hydrodynamic forces approximated using the reference hydrodynamic coefficients and CFD based coefficients, shown in Fig. 1, revealed that sway force Y'_H estimated using CFD based coefficients is

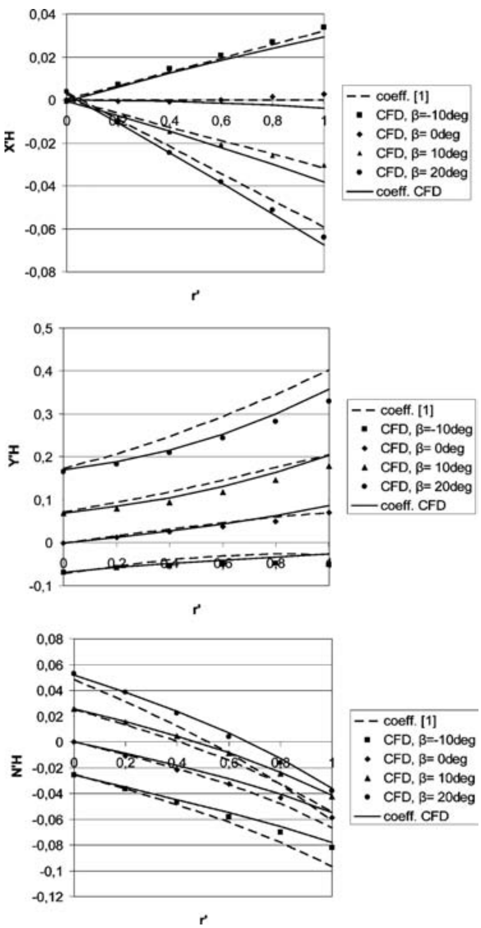

Figure 1. Surge force X'_H, sway force Y'_H, and yaw moment N'_H computed with CFD and approximated using coefficients given in [1] (dashed line) and CFD estimated (solid line).

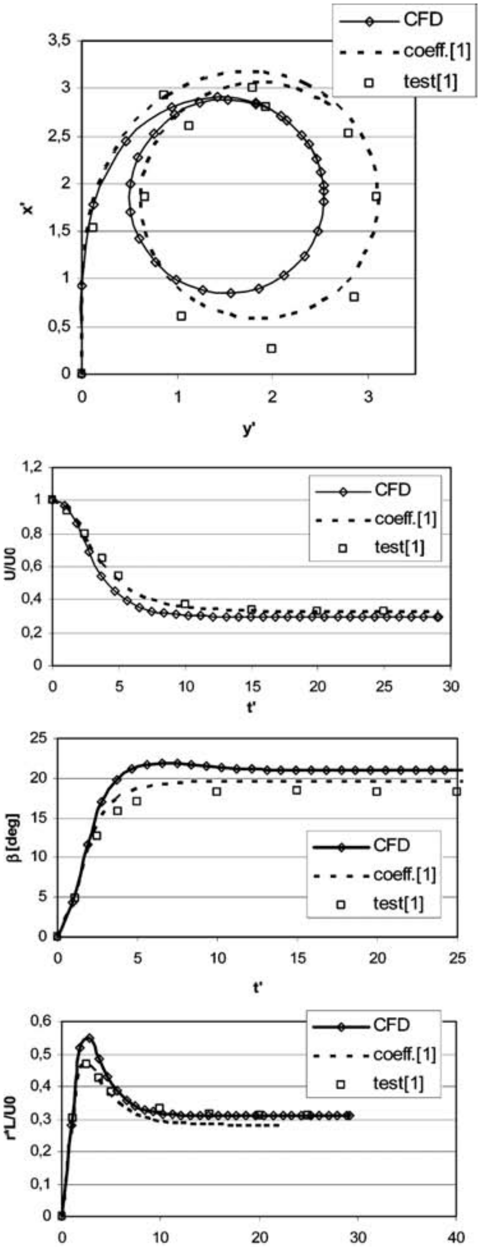

Figure 2. Turning circle of model ship with $\delta = 35$ deg simulated using hydrodynamic coefficients from [1] and coefficients based on CFD computations.

evidently underestimated at drift angles above 10 deg. Yaw moment N'_H is overpredicted at drift angles above 10 deg and at high yaw rates $r' > 0.4$. That differences in estimation of hydrodynamic forces are reflected also in results of simulations shown in figures 2 and 3.

Taking into account that discrepancies in force estimation and in simulated turning circle appear at higher values of drift angle and yaw rate, one may suspect that

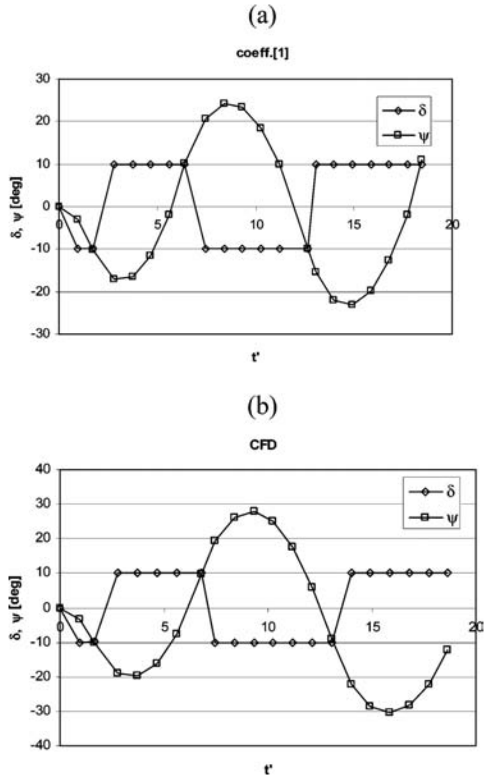

Figure 3. 10/10 deg zig-zag manoeuvre of model ship simulated using hydrodynamic coefficients from [1] (a) and coefficients based on CFD computations (b).

the assumption of low Froude number applied to computations of ship flow is valid only at low drift angle and yaw rate. Then at higher values of drift angle and yaw rate the ship heel, trim, sinkage, and especially the effect of free water surface around the ship cannot be neglected in CFD computations.

ACKNOWLEDGEMENT

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2.3 New capabilities of the NTPRO 4000 full mission ship handling simulator in the assessment and evaluation processes at Lithuanian Maritime Academy

R. Zažeckis, I. Bartusevičienė & R. Maksimavičius
Lithuanian Maritime Academy, Klaipeda, Lithuania

ABSTRACT: Nowadays the equipment used on ships is becoming more and more sophisticated, safety of shipping depends heavily not only on trustworthiness of high-tech products, but also on mariners' competence. It is necessary to find methods to enable seafarers to keep track with technical developments. Simulators as a tool combined with a properly developed course curriculum and qualified instructors provide an appropriate method not only for training, but also for measuring, assessing and evaluating individual mariner performance in order to test levels of competency and proficiency. According to Nieri (1995, p. 1/6), "The development of performance-based assessment tools would utilize the widely-recognized advantages of simulators and part-task trainers to generate a scenario in which the license candidate must demonstrate his knowledge of system relationships, knowledge of operational procedures, monitor systems and situations, respond to unexpected occurrences, identify and diagnose problems, and manage personnel, in a dynamic world". This paper discusses the usage of new capabilities of the NTPRO 4000 full mission ship handling simulator in the assessment and evaluation processes at Lithuanian Maritime Academy.

1 INTRODUCTION

Simulators are widely used for different educational purposes, such as learning, training, research, formative and summative assessment and evaluation, not only in maritime education and training, but also in aviation, nuclear power plants (Ham et al., 2008), medicine: surgery (Cosman et al., 2002; Maithel et al, 2006), nursing (Decker et al., 2008). Simulations are example of technology enabling learning to be done more easily and effectively (Biggs & Tang, 2008) in a safe and controlled environment. As technology is developing rapidly the simulators become more popular educational mean.

Over last few decades there was a huge growth of automated navigation systems. More and more systems making navigator's job easier came on the scene. It has begun with global positioning systems (GPS) and nowadays grown into electronic chart display and information systems (ECDIS). There is no doubt that new sophisticated systems facilitate navigator's job and ensure safer navigation. For example, the study of Gould et al. (2009) proved that ECDIS appeared to improve navigation performance compared to conventional navigation based on paper charts. Although this fact was proved under normal conditions and more investigations should be under high-workload conditions and in the presence of other stressors. Habit to use sophisticated (automated) systems sometimes have negative impact to the qualification of the navigator, as captain can lose his proficiency in using usual navigational means because of permanent usage of automated navigation systems. It is obvious for the experienced navigators that modern navigation equipment today still is not perfect.

Refusing the traditional means of navigation, question of navigational safety may arise in case of the failure or malfunctions of automated navigation system, because during initial study stage attention to the traditional navigational tasks slacks as student contemplates that use of traditional navigational tasks is not relevant, but this can be designated as lack of navigators qualification, where qualifications are well-defined in STCW (Standards of Training, Certification and Watch keeping) convention.

Improvement of navigational systems tended to facilitate safer navigation and load of the additional tasks to the navigator increased requirements to the qualification of seafarers. As a consequence teaching process and teaching aids had to be improved. So navigational simulators able to simulate different navigational situations and to ensure that student is able to clarify different solutions of navigational task and implement the very best solution in certain circumstances were implemented to education and training process of navigators.

Usage of simulators is the best solution for the analysis of the actions taken by the students during the performed tasks and for the understanding of the competence of students. The diagnostics and analysis of mistakes will allow avoiding possible mistakes, which may arise in different navigational situations.

During the education and training process most of the mistakes are analyzed theoretically before the usage of the simulator. However nowadays the instructors are practically able to allow students to make mistakes using technologies of the modern simulators and show the possible consequences of the mistakes to students without real damage to the environment. Possibility to observe mistakes during performance of special navigational tasks helps to make appropriate decision about the competence of the student not only in routine, but also in emergency situations.

NTPRO 4000 full mission ship handling simulator is used continuously in the process of education and training of navigators in Lithuanian Maritime Academy. Two years ago the new capability in TRANSAS NTPRO 4000 called the TRANSAS Evaluation and Assessment System (TEAS) was implemented. The new capability allows assessing objectively the correctness of an exercise performance by a trainee on NTPRO 4000 navigation simulator. This opportunity is used continuously during all learning process for the formative assessment. According to Brown & Glasner (1999), good assessment (formative or summative) has to be valid, reliable, practical, developmental, manageable, cost-effective, fit for purpose, relevant, authentic, closely linked to learning outcomes and fair. In formative assessment, the results are used to improve learning: students can make mistakes: "the error detection is the basis for error correction" (Biggs & Tang, 2007, p. 164). It's completely different in summative assessment and evaluation: the results of such an assessment are used to grade or certificate students at the end of a course or program. According to Biggs & Tang (2007), error no longer is there to instruct, as in formative assessment: error now signals punishment. That's why much more attention should be paid for the final examination, where complex assessment evaluates not only how each part of knowledge is soaked up, but also how all knowledge and skills are implemented in close to real situation in real time. The TEAS gives this possibility.

For two years the TEAS of NTPRO 4000 full mission ship handling simulator has been used for summative assessment and evaluation during final examination at Lithuanian Maritime Academy. The authors are still searching the ways to improve objectivity, validity and reliability of the final evaluation of the students. Some results of this experience are presented in the article.

2 MANDATORY MINIMUM REQUIREMENTS FOR CERTIFICATION OF OFFICERS

It is well-know that mandatory minimum requirements for certification of officers in charge of navigational watch are well-defined in STCW code. The code clearly states the standards of competence that every candidate for certification shall be required to demonstrate: the competence to undertake at operational level, the tasks, duties and responsibilities are listed in column 1 of STCW code table A-II/1; the minimum knowledge, understanding and proficiency required for certification is listed in column 2 of STCW code table A-II/1; the level of knowledge of subjects listed in column 2 of STCW code table A-II/1 shall be sufficient for officers of the watch to carry out their watch keeping duties; every candidate for certification shall be required to prove evidence of having achieved the required standard of competence in accordance with methods for demonstrating competence tabulated in columns 3 and 4 of STCW code table A-II/1.

With reference to above mentioned TRANSAS NTPRO 4000 simulator (especially the TEAS) is an appropriate solution solving the student's certification problems in LMA.

2.1 *Possible competency assessment using NTPRO 4000*

Most of the educational programs during the process of education and training of navigators are accomplished with reference to STCW code. The same requirement corresponds to assessment and evaluation process. Assessment and evaluation in accordance to STCW code requirements can be improved using the NTPRO 4000 TEAS because this system allows assessing the navigator's competences stated in STCW code (table 1).

In most cases the basic ordinary training and assessment systems are applied. The process of basic training and assessment system is presented in fig. 1.

The more detailed description of the certain exercise using NTPRO 4000 will be more complicated and will look like in fig. 2.

Several exercises according to the number of competences intended to assess can be included to overall assessment (e.g. final examination). Evaluation of each exercise has its own particular weight and influences as a part of the overall assessment and evaluation the final decision about competency of the trainee.

The thorough explanation of typical example of above-mentioned detailed exercise is presented in fig. 3:

It is important to mention that only above mentioned competencies (table 1) can be assessed and evaluated using NTPRO 4000 TEAS in present time, the other competencies defined in STCW code are evaluated in particular training during common examinations.

3 EVALUATION AND ASSESSMENT PROCESS USING NTPRO 4000 TEAS

Taking into consideration all the mentioned above, final decision for issuing the Certificate of Competency is made using the complex assessment.

Complex assessment involves competences mentioned in 2.1 (table 1) and additional competencies which were evaluated in particular training.

Table 1. The list of competences, which could be assessed using NTPRO 4000 TEAS.

1. Plan and conduct a passage and determine position:
   1.1. Ability to determine the ship‘s position by use of:
   1.2. Ability to use navigational charts and publications, such as sailing directions, tide tables, notices to mariners, radio navigational warnings and ship’s routing information.(ECDIS systems are considered to be included under the term “charts”);
   1.3. Ability to determine the ship‘s position by use of electronic navigational aids;
   1.4. Ability to operate echo sounders and apply the information;
   1.5. Ability to determine error of the magnetic and giro compasses and to allow for such errors;
   1.6. Knowledge of steering control systems, operational procedures and change-over from manual to automatic control and vice-versa. Adjustment of controls for optimum performance;
   1.7. Ability to use and interpret information obtained from shipborn meteorological instruments;
   1.8. Knowledge of the characteristics of the various weather systems, reporting procedures and recording systems;
   1.9. Ability to apply the meteorological information available.

2. Maintain a safe navigational watch:
   2.1. Thorough knowledge of the content, application and intent of the International Regulations for Preventing Collisions at Sea;
   2.2. Thorough knowledge of the basic principles of keeping a navigational watch;
   2.3 Thorough knowledge of effective bridge team work procedures;
   2.4. The use of routeing in accordance with the General provisions on Ship‘s Routeing.

3. Use of Radar and ARPA to maintain safety of navigation:
   3.1. Performance including:
      3.1.1. Factors effecting performance and accuracy;
      3.1.2. Setting up and maintaining displays;
      3.1.3. Detection of misrepresentation of information, false echoes, sea return, etc., racons and SARTs;
   3.2. Use including:
      3.2.1. Range and bearing; course and speed of other ships; time and distance of closest approach of crossing, meeting overtaking ships;
      3.2.2. Identification of critical echoes; detecting course and speed of other ships; effect of changes in own ship‘s course or speed or both;
      3.2.3. Application of the International Regulations for Preventing Collisions at Sea;
      3.2.4. Plotting techniques and relative and true motion concepts;
      3.2.5. Parallel indexing;
   3.3. Principal types of ARPA , their display characteristics, performance standards and the dangers of over reliance on ARPA;
   3.4. Ability to operate and to interpret and analyze information obtained from ARPA, including:
      3.4.1. System performance and accuracy, tracking capabilities and limitations, and proceeding delays;
      3.4.2. Use of operational warnings and system test;

(*Continued*)

Table 1. Continued

      3.4.3. Methods of target acquisition and their limitations;
      3.4.4. True and relative vectors, graphic representation of target information and danger areas;
      3.4.5. Deriving and analyzing information, critical echoes, exclusion areas and trial manoeuvres.

4. Respond to emergences
   4.1. Emergency procedures:
      4.1.1. Precautions for the protection and safety of passengers in emergency situations;
      4.1.2. Initial action to be taken following a collision or a grounding; initial damage assessment and control;
      4.1.3. Appreciation the procedures to be followed for rescuing persons from sea, assisting a ship in distress, responding to emergencies which arise in port.

5. Respond to a distress signal at sea;
   5.1. Knowledge of the contents of the IMO Merchant Ship Search and Rescue Manual (MERSAR).

6. Use the IMO Standard Marine Communication Phrases and use English in written and oral form;
   6.1. Adequate knowledge of the English language to enable officer:
      6.1.1. To use charts and other nautical publications;
      6.1.2. To understand meteorological information and messages concerning ship‘s safety and operation;
      6.1.3. To communicate with other ships and coast stations;
      6.1.4. To perform the officer’s duties with a multilingual crew;
      6.1.5. To use and understand the IMO Standard Marine Communication Phrases.

7. Transmit and receive information by visual signalling;
   7.1. Ability to transmit and receive signals by Morse light;
   7.2. Ability to use the international Code of Signals.

8. Manoeuvre the ship;
   8.1. Knowledge of ship manoeuvring and handling:
      8.1.1. The effects of dead-weight, draught, trim, speed and under keel clearance on turning circles and stopping distances;
      8.1.2. The effects of wind and current on ship handling;
      8.1.3. Manoeuvres and procedures for the rescue of person overboard;
      8.1.4. Squat, shallow water and similar effects;
      8.1.5. Proper procedures for anchoring and mooring

The additional competences of the students, such as use of ARPA, ECDIS, usually are evaluated before the final examination using NTPRO 4000 by Lithuanian Maritime Safety Administration in accordance with IMO Model Course 1.07 for ARPA, and IMO Model Course 1.27 for ECDIS; and the results are the basis for the diploma of the competency. Although the assessment of mentioned competences is a part of complex assessment as the student must show his ability to implement all of competences required by STCW code, and especially use not only of automated

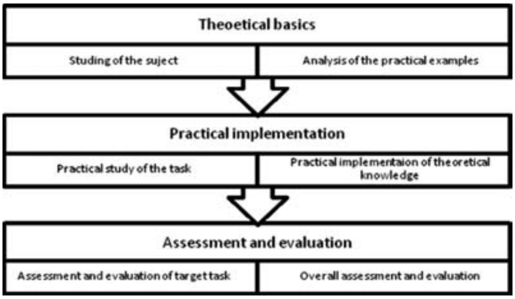

Figure 1. Basic training and assessment system in LMA.

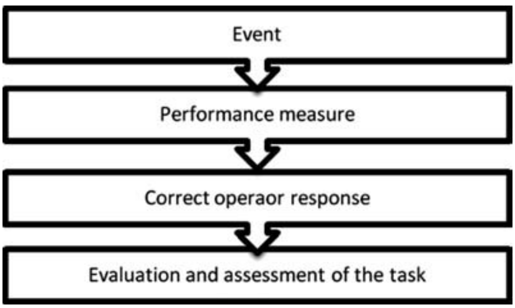

Figure 2. Detailed exercise.

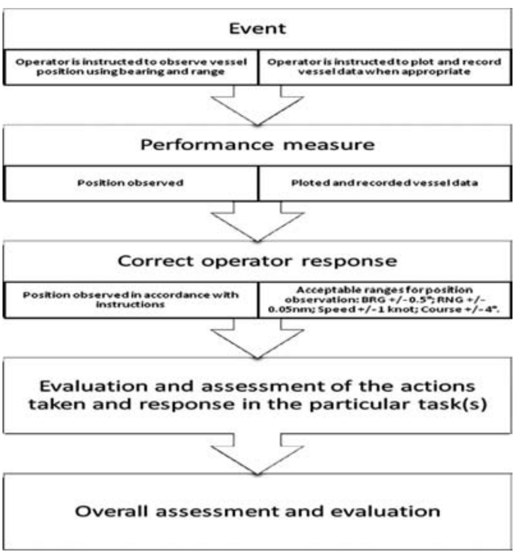

Figure 3. Example of detailed exercise.

navigation systems, but also the solutions of traditional navigational tasks in real time simulation.

The overall complex assessment and weight of assessed tasks can be presented in fig. 4.

During all complex assessment process correct and incorrect actions and responses are electronically logged additionally and established paper log book is filled, as not all competences can be logged electronically.

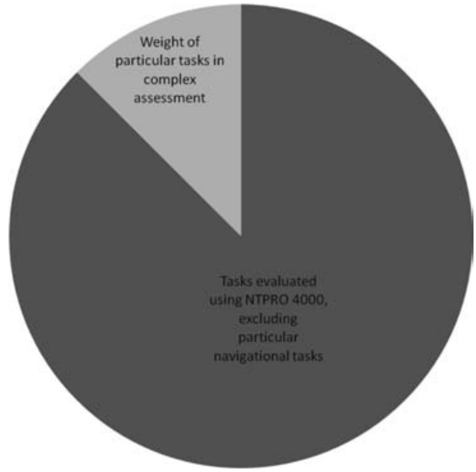

Figure 4. Overall complex assessment.

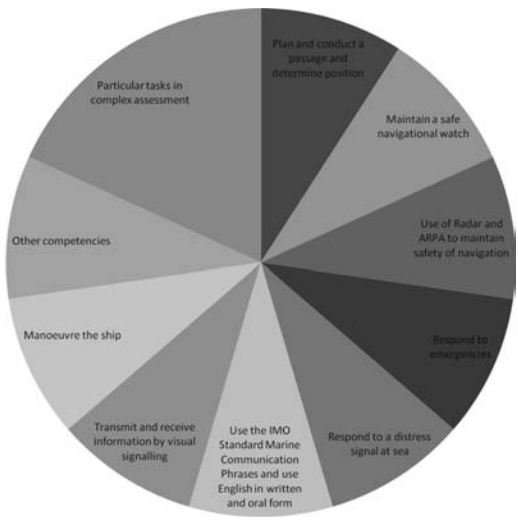

Figure 5. Detailed chart of complex assessment.

It is important that employing TEAS the percentage system of evaluation should be applied; it means that student comes to assessment with the score of all competencies 100%, and later he gets penalty points for any failed navigational task. Penalty points are multiplied by weight of the task evaluated, so final evaluation result E can be expressed by formula:

$$E = 100 - (P_1 w_1 + P_2 w_2 + \dots + P_n w_n) = 100 - \sum P_n w_n$$

Where: P_n – penalty point for appropriate task; w_n – weight of the penalty point.

If there is necessity in more accurate results of competence evaluation each task can be evaluated separately with its penalty points (applying the same formula), influencing final evaluation.

Detailed assessment chart is presented in fig. 5, extraction of the competence evaluation in overall complex assessment is presented in fig. 6.

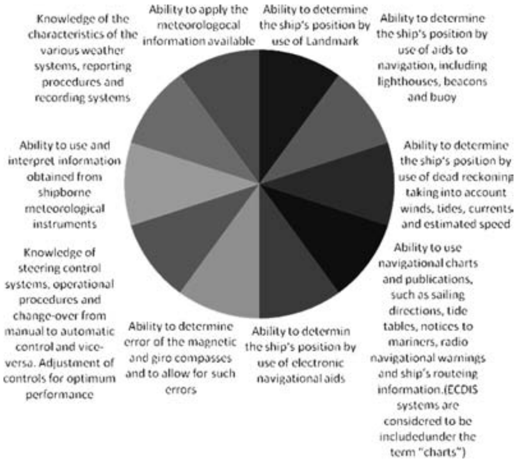

Figure 6. Extraction from overall complex assessment for "Plan and conduct a passage and determine position" competence.

During evaluation and assessment process all mentioned competencies in 2.1 (table1) are thoroughly checked, especially competencies used to solve traditional navigational tasks. As TEAS system electronic logbook, paper logbook is employed, the subjective assessors' opinion is minimized, and it allows making the very correct and objective decision about the competency and suitability for appropriate position of the student.

In other words the assessment using NTPRO 4000 is based on the check of the exercise fulfilment correctness with regard to the selected set of criteria. The criteria check consists in comparing the exercise "assessment parameters" to the set limit values according to the set "rule". At each moment of time a relative error is recorded (relative deviation of the "assessment parameter" from the limit values) and penalty points are calculated as a function of the relative error and the "error weight".

The overall sum of penalty points in the observation interval is calculated as a sum of penalties at each moment of time by each "assessment parameter".

The trainee competency is assessed in points (Score %) starting from 100% minus penalty score. The correctness of the exercise fulfilment can be assessed after the end of the exercise during the playback of the exercise log. The Training Report is created automatically at the moment when the log file is loaded. Competency assessment can be obtained in the process of the exercise and after its end as well. For the final assessment of the trainee competency, the "Passing score" is entered.

This process allows making objective judgement about student's competency and enable saving published the results for longer time.

4 PRACTICAL EXAMPLE

Extraction from practical evaluation and assessment of Use of Radar and ARPA to maintain safety of navigation is presented below. Ability to operate and to interpret and analyse information obtained from the radar, including factors affecting performance and accuracy of the trainee is tested.

The exercise is set in adverse visual and radar observation conditions (fog, rough se, rain). The trainee is assigned with a task to proceed in restricted waters with narrow passage making a 90˚ turn round the buoy (which becomes a reference point) at a set distance with a margin equal to the possible radar range measurement error. Penalty Charge value is entered.

The trainee must adjust the optimum radar picture quality, identify the buoy echo among the clutter and perform the required manoeuvre.

Evaluation is made through the exercise. Performance criteria – actual distance to reference point must be near the limit defined (if the actual distance exceeds defined limits, penalty charge are imposed, here in this example-30% if grounding occurs- 70%).

Calculations of the assessment for this particular task will look as follows:

$$E_{radar} = 100\% - (P_l w_l + P_g w_g) = 100\% - (30 \cdot 1 + 100 \cdot 0{,}7) = 0$$
$$E_{radar} = 100\% - (P_l w_l + P_g w_g) = 100\% - (30 \cdot 1 + 0 \cdot 0{,}7) = 70$$
$$E_{radar} = 100\% - (P_l w_l + P_g w_g) = 100\% - (0 \cdot 1 + 0 \cdot 0{,}7) = 100$$

Where: P_l-penalty for exceeded limit, P_g-penalty if the grounding occurs, *w*-weight of the penalty in particular exercise.

As seen above, depending on the trainee's ability to accomplish exercise, he gets final evaluation for the particular task, which is a part of the complex assessment during final examination.

5 CONCLUSIONS

- During initial stage of study attention to the traditional navigational tasks slacks as student contemplates that use of traditional navigational tasks is not relevant.
- Use of navigation simulators enables to test all competencies in accordance with STCW code especially solving traditional navigational tasks, final examination using NTPRO 4000 TEAS based on methods described in the paper may be basis for certification of competency.
- Using TEAS the percentage system of evaluation is applied, it is predicted that student gets the score of 100% at the beginning of the assessment, and later points for any failed navigational task multiplied by weight are subtracted from initial 100 % in order to get final evaluation.
- Lithuanian Maritime Academy uses new capability of NTPRO 4000 not only during training process by performing formative assessment but also for the summative assessment and evaluation of students' competency during final examination.
- Assessors are representatives and persons approved by Lithuanian Maritime Safety Administration; this enables getting the Certificate of Competence after final complex assessment in Lithuanian Maritime Academy.

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2.4
Reconstructing a marine casualty: The effectiveness of the full-mission simulator as a casualty analysis tool

E. Doyle
Cork, Ireland

ABSTRACT: The primary purpose of a marine casualty investigation is to seek to establish the causal factors of the casualty with a view to learning the hard lessons and avoiding a repetition.

The broad questions of an investigation: "who?, what?, when?, where?, why?, and how?", all help to uncover the facts. The investigation sequence will cover a diverse range of fact-finding activities, amongst which, as often the case, may be a requirement for "conducting specialised studies". Following the fact-finding stage the typical investigation progresses to analysis of the facts, reaches conclusions and makes recommendations.

Keeping an open mind, to avoid premature conclusions, requires the separation of the fact-finding and analysis phases. But the analysis may well help to identify missing pieces of evidence, or different lines of enquiry that may otherwise have gone undetected. As an effective reconstruction tool, a full-mission bridge simulator offers an opportunity to examine a broad spectrum of environmental conditions and vessel characteristics, as well as equipment failures, human factors and operating procedures. A casualty incident can be reconstructed in a real-time simulated environment, to aid more detailed analysis.

Within the usual confines of the legal process, comprehension of nautical 'black magic' is greatly simplified for non-mariners, by seeing the simulated casualty incident unfold, in real-time or in selected short-time segments.

1 REGULATION AND BEST PRACTICE IN MARINE SAFETY INVESTIGATION

1.1 *Casualty investigation code*

The global harmonisation of marine casualty investigation was taken a step further last year with the approval by the International Maritime Organization of the new Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident (Casualty Investigation Code). The Maritime Safety Committee adopted the Casualty Investigation Code by resolution MSC.255(84). And a new regulation 6 in chapter XI-1 of the SOLAS Convention was also adopted (resolution MSC.257(84)), giving mandatory status to the Code, which takes effect on 1 January 2010. However, the IMO has invited Governments to start implementing the new Code on a voluntary basis prior to the effective date of the Code.[i]

1.2 *Common approach of 1997*

This most recent Code incorporates and builds on the best practices in marine casualty investigation that were established by the IMO's Code for the Investigation of Marine Casualties and Incidents, adopted in November 1997. That Code sought to promote co-operation and a common approach to marine casualty and marine incident investigations between States. While the new Code specifies some mandatory requirements, it does recognize the variations in national laws in relation to the investigation of marine casualties and incidents. But the broad aim is to facilitate and promote objective marine safety investigations for the benefit of flag States, coastal States, and the shipping industry in general.

1.3 *Objectives and purpose*

The objectives and purpose are well stated in the Code's opening chapter:

> "1.1 The objective of this Code is to provide a common approach for States to adopt in the conduct of marine safety investigations into marine casualties and marine incidents. Marine safety investigations do not seek to apportion blame or determine liability. Instead a marine safety investigation, as defined in this Code, is an investigation conducted with the objective of preventing marine casualties and marine incidents in the future. The Code envisages that this aim will be achieved through States:
>
> 1. applying consistent methodology and approach, to enable and encourage a broad ranging investigation, where necessary, in the interests of uncovering the causal factors and other safety risks; and
> 2. providing reports to the Organization to enable a wide dissemination of information to assist the international marine industry to address safety issues."

1.4 *Causal factors rather than blame or fault*

As we can see, the primary purpose of a casualty investigation is to seek to establish the causal factors of the casualty with a view to learning the hard lessons and avoiding a repetition. And while it is not, and never should be, the role of a marine safety investigation team to attribute blame or fault, that is not to say the investigating authority should refrain from fully reporting the causes because fault or liability might be inferred from its findings.

2 THE FACT-FINDING/ANALYSIS CONUNDRUM

2.1 *Uncovering the facts*

The investigation must attempt to uncover all the facts, by seeking answers to such fundamental questions as: "who?, what?, when?, where?, why?, and how?" In this regard, the fact-finding sequence of the investigation is likely to include such activities as:

- inspecting the location;
- gathering or recording physical evidence;
- interviewing witnesses;
- reviewing of documents, procedure and records;
- conducting specialised studies (as required);
- identifying conflicts in evidence;
- identifying missing information; and
- recording additional factors and possible underlying causes.

2.2 *Progression to analysis*

Following the fact-finding stage a typical marine casualty or incident investigation includes: analyses of the facts; conclusions; and recommendations.

2.3 *Fact-finding and analysis*

Investigators need to keep an open mind and avoid reaching conclusions too early. It may appear self-evident that the fact-finding stage of the process should be separate from the analysis. But it must always be borne in mind that the analysis may well help to identify missing pieces of evidence, or different lines of enquiry that may otherwise have gone undetected.

2.4 *Simulator as effective reconstruction tool*

In the course of very many marine safety investigations, the availability of a full-mission bridge simulator is likely to offer a powerful and productive analytical tool. Such a tool affords the opportunity to examine a broad spectrum of environmental conditions and vessel characteristics, as well as equipment failures, human factors and operating procedures. A marine casualty may be reconstructed in a real-time simulated environment, to allow detailed analysis of the incident. Mariners who have had the benefit of full-mission simulator training will readily appreciate the merits of the debriefing/playback feature, allowing detailed examination of the exercise or simulated incident, as the replay unfolds in real-time or short-time segments.

2.5 *Investigation and legal proceedings enhanced*

Such simulation can be replayed at will, with very obvious benefits for expediting the work of the marine safety investigation team. In another forum, such as the civil judicial process, it has the added benefit for non-mariners of aiding the comprehension of nautical terminology with the consequent potential to expedite settlement.

3 COLLISION CASE STUDY

3.1 *Investigation and litigation*

A practical example of the potential beneficial analysis that a simulated examination might generate is given from the following marine casualty case study. It centers on a collision off the southeast coast of Ireland, in June 2000. The collision was investigated by the newly established Marine Casualty Investigation Board (MCIB)[ii], who did not have access to adequate simulation facilities at that time. The case also generated High Court proceedings which, in the event, were settled shortly before the scheduled hearing.

3.2 *Summary of the incident*

On the morning of 13 June 2000, the beam trawler mfv STELIMAR (LOA 19m, 200t) was on passage from her home port of Dunmore East, heading towards her usual fishing grounds. She was steering a course of about 145, and making about 8.5 knots. The weather was fair: Wind SW'ly F 3/4, with good visibility.

At the same time, the tanker mv ALMANAMA (LOA 249m, 97,000 dwt) was making a course of 256°, speed 13.8 knots, bound for Cork Harbour. The vessel had cleared the traffic separation scheme at Tuskar Rock and was now on a course that would take her across the path of STELIMAR. In fact, the two vessels were on converging courses, in circumstances where the bearing between them was not changing significantly — a collision seemed inevitable unless avoiding action was taken by one or both vessels.

This was a classic "crossing situation" for which there is clear provision in the COLREGS. Rule 15 obliged ALMANAMA, as the give-way vessel, to keep out of the way and thus avoid collision, while Rule 17 required STELIMAR, the stand-on vessel, to maintain her course and speed — in the early stage of the encounter, at any rate.

In the event, a collision did occur, at a position about 14 miles SSE of Hook Head. STELIMAR sustained substantial damage, which necessitated her being towed back to Dunmore East. Given the enormous disparity in the size and tonnage of the two vessels it was nothing less than incredible good fortune that STELIMAR did not capsize and founder.

In addition to her Rule 15 obligation, ALMANAMA was also required by Rule 16, to "... take early and substantial action to keep well clear." In discharging her obligations, ALMANAMA could have made a large alteration of course to starboard so as to make her intentions very clear to the stand-on vessel, or she could have made a substantial reduction to her speed but this action would not have been so readily apparent to the stand-on vessel. Accepting that speed reductions are rarely used by give-way vessels when taking avoiding action in open sea situations, ALMANAMA could reasonably have been expected to make a substantial alteration of course to starboard. Further, she should have done so at an early stage in the encounter so as to avoid putting STELIMAR in the unnecessary and difficult position of having to take avoiding action under Rule 17(a)(ii).

3.3 *'Factual' conflict*

The MCIB investigation report noted the "Factual Report of the Collision..." from STELIMAR's perspective, and a similar "Factual Report..." from ALMANAMA. There should be no surprise that these 'factual reports' were in conflict. The real surprise was that the MCIB analysis failed to resolve the conflict adequately.

3.4 *STELIMAR's perspective*

STELIMAR'S skipper first noticed a large merchant vessel visually, broad on his port bow at a distance of 6 or 7 miles, on a general W'ly heading, shaping to cross his path — she would need closer attention as the range closed.

When the radar image of this large ship, soon to be identified as ALMANAMA, first appeared at the extremity of his 3-mile radar display, the skipper began to pay continuous attention to her progress. He believed that she was making 14 or 15 knots, and his concern was heightened by the developing situation, as presented in Fig. 1: he was in a crossing situation with a large vessel, whose bearing appeared to remain the same or nearly so.

3.5 *Imminent collision*

When the vessels were about 1.5 miles apart, and ALMANAMA had still not altered course, STELIMAR came to the conclusion that he would have to take avoiding action.

He could have altered course to starboard but the skipper felt this would have prolonged the period of uncertainty. In the event, he chose to de-clutch the main engine and allow STELIMAR'S speed to quickly run down. He estimated he did this when the vessels were about 0.75 to 0.5 miles apart — or about 2 to 2.5 minutes before impact.

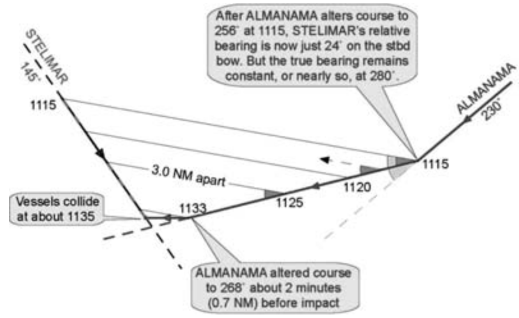

Figure 1. A reconstruction of the crossing encounter.

In taking the speed off his vessel the skipper anticipated that ALMANAMA would pass safely ahead of him. However, very shortly afterwards (perhaps when 0.5 to 0.25 miles apart) he was alarmed to see a man on ALMANAMA'S starboard bridge wing running into the bridge in an agitated state. He was deeply concerned at this and, believing that he now had a full emergency on hand, he put his engine to "Full astern". He estimates the two vessels were about 0.25 miles apart at this point and that he was at "Full astern" for 30 to 40 seconds until the collision. He believed that ALMANAMA was turning slowly to starboard, towards STELIMAR as she gained stern-way.

3.6 *ALMANAMA's perspective*

Meanwhile, the "Factual Report..." from the other vessel has the OOW on the bridge of ALMANAMA, plotting a fix for 1115 and altering course to 256°. The vessel's speed was about 13.8 knots.

At 1120 he observed a small target (STELIMAR) some 40° to 50° on the starboard bow at a distance of 5 or 6 miles. He claims he acquired and plotted this target on the ARPA, which predicted a CPA of 1 to 1.5 miles with the target crossing ahead. He also took a series of visual bearings, which indicated that the vessel was passing ahead, but did acknowledge that the bearings were changing very slowly. He estimated that the fishing vessel was heading on a course of about 150° at about 10 or 11 Knots.

When the fishing vessel was between 2.5 and 3.5 miles off and about 1.5 to 2.5 points on the starboard bow, the OOW tried to call it on VHF Channel 16, but there was no reply from STELIMAR.

3.7 *Belated course alteration*

He now altered course to starboard, to 268°, though the fishing vessel was still fine to starboard and about 1 mile off. He claimed that STELIMAR altered course to port to about 120° and possibly reduced speed also. ALMANAMA then applied hard-to-port helm in a final, and ultimately vain, attempt at trying to avoid collision.

4 CLOSE-QUARTERS ANALYSIS

4.1 *Course recorder trace*

ALMANAMA's course recorder trace confirmed her course alteration from 230° to 256° at 1115. It also showed that her next course alteration, to 268°, was made just about two minutes prior to the collision, and that the hard-to-port manoeuvre had practically no effect before impact.

4.2 *Hard lesson on failure to "take early and substantial action"*

Deconstruction of the final phase of this collision encounter was clear to all; STELIMAR took emergency "full astern" action when it seemed clear to her that collision could not otherwise be avoided, but the action was unsuccessful because the beneficial effect of her stern-way motion was nullified by the very belated turn to starboard by ALMANAMA, culminating in the collision.

4.3 *Making relative velocity simple*

The most glaring and unresolved conflict between the two parties was ALMANAMA's contention that STELIMAR was expected to cross ahead at a CPA of 1 to 1.5 miles, this information allegedly predicted from ARPA. Such contention is readily refuted by means of a standard relative velocity plot, though not so readily understood by non-mariners. However, the use of a bridge simulator easily overcomes those difficulties.

4.4 *Construction of RelVel triangle*

The veracity of the relative velocity information is dependant on the vector accuracy for each ship. In the case of ALMANAMA, her course and speed were established from log records and instrumentation, while STELIMAR's course and speed were consistent with her recent departure (about 2 hours) from her home port. Reversing the vectors from the collision point allows construction of the basic relative velocity triangle, as given in Fig. 2. Because of uncertainty in the precise timing of each vessel's movements in the final moments of the encounter the plot may contain an inherent error, but nothing of any significant consequence. This was confirmed by rerunning the incident as a test exercise on the NMCI bridge simulators.

4.5 *Critical relative bearings*

Given the geometry of this encounter, as outlined at Fig. 1, it will be seen that STELIMAR was bearing 280° from ALMANAMA, or 50° on her starboard bow before she altered course at 1115. The contention that STELIMAR was observed at 1120, about 40°/50° × 5/6 miles on ALMANAMA's starboard bow, conflicts with the Fig. 1 plot which shows that the vessels were no more than 4.4 miles apart then. It is certainly the case that STELIMAR could not have been seen 50° on the bow at any time **after** ALMANAMA altered course at 1115 — if it were so, a collision could not possibly have happened. The only rational conclusion is that STELIMAR was seen broad (50°) on the starboard bow **before** ALMANAMA altered course to 256°.

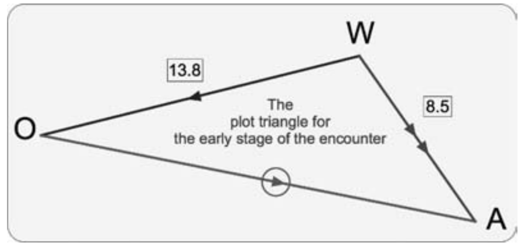

Figure 2. The Relative velocity triangle, from ALMANAMA's perspective.

Figure 3. The ARPA simulation displays a 'true' vector from the acquired target on ALMANAMA's starboard bow.

5 ARPA SIMULATION

5.1 *ARPA vectors — 'true' or 'relative'?*

The change in the relative bearing of STELIMAR (from 50° on the bow, drawing left to 24°) may well have misled the OOW on ALMANAMA into believing that STELIMAR was crossing clear ahead of his own vessel. It is also possible that he confused the "true" and "relative" vector information presented by his ARPA radar. In any event, he chose to disregard (until too late) the warning of his own eyes when he observed that the compass bearing of STELIMAR was changing only very slowly.

5.2 *ARPA information*

The simulated ARPA display in Fig. 3 presents an early stage of the encounter from the ALMANAMA perspective; her course is 256°, and STELIMAR (the acquired target) is bearing 281° (25° on the starboard bow), range 5.1NM. The target's 'true' vector is clearly visible, indicating a crossing condition.

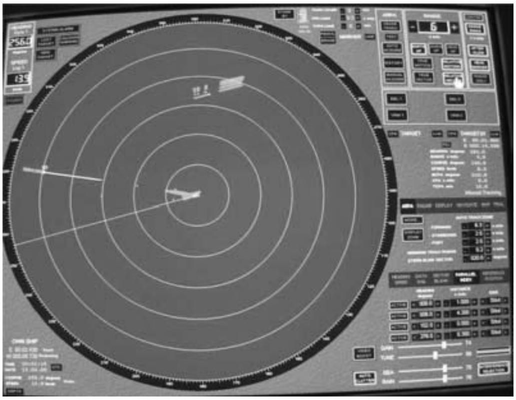

Figure 4. The target's 'relative' vector signals a developing collision condition.

A short time later, as presented in Fig. 4, the navigational situation remains the same but the ARPA vector presentation is now 'relative'. On any normally functioning and operated ARPA equipment, this developing close-quarters situation will trigger all the usual audible and visible alarms.

6 CONCLUSIONS

As demonstrated in this case study, full-mission bridge simulation lends itself easily and readily to collision analysis. The incident was reconstructed in a real-time simulated environment, aiding the more detailed analysis than that offered in the MCIB report. The simulator reconstruction exposed possible equipment failure, human factors and shortcomings in operating procedures. These are weaknesses that frequently flag missing evidence, which in turn, prompt investigators to pursue different lines of enquiry. The complexity of nautical technology is greatly simplified by a simulated reconstruction, which has clear benefits for all parties within the strictures of the legal process.

REFERENCES

[i] IMO, 2008. The Maritime Safety Committee, at its eighty-fourth session (7 to 16 May 2008), adopted the Casualty Investigation Code by resolution MSC.255(84) and a new regulation 6 in chapter XI-1 of the SOLAS Convention by resolution MSC.257(84) to make the Code mandatory. The Committee agreed that the Casualty Investigation Code should take effect on 1 January 2010, noting that the effective date should be the same as the date of entry into force of the new SOLAS regulation XI-1/6.

[ii] MCIB, 2005. Investigation Report by the Marine Casualty Investigation Board into ALMANAMA/STELIMAR collision.

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2.5
Fuzzy fast time simulation model of ship's manoeuvring

P. Zalewski
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: The paper presents a concept of fuzzy FTS (Fast Time Simulation) model of twin-screw ship manoeuvring autonomously (without tugs) in confined waters. The conceptual model has been based on the fuzzy logic controller with expert database formed by manoeuvres obtained from the real-time non-autonomous trials classified in relation to expert manoeuvre impact on ship's advance, lateral and rotation speed and her position in reference to the present ship status. Exemplary pitch controller for vessels with two propellers at specified hydro-meteorological conditions has been presented.

1 INTRODUCTION

Fuzzy set theory has been used successfully in virtually all the technical fields including control, image/signal processing and expert systems. One of the most successful applications however seems to be in the control field where the theory can utilize the human control operator's knowledge and experience to intuitively construct models so that they can emulate human control behaviour to a certain extent (Ying 2000, Zadeh 1996).

Simulation studies give perfect opportunity to record the expert knowledge of pilots commanding vessels in the relevant area. An essential problem of the acquisition and representation of navigator's knowledge referring the conduct rules (procedural knowledge) and the analysis and evaluation of navigational situation (declarative knowledge) can be solved by gaining knowledge directly from electronic records made during such research and creation of the expert knowledge database can finally lead to finally to the concept of autonomous ship control during FTS in confined waters. Fast time simulation can be achieved easily by applying shorter period of state change than established in the ship's hydrodynamic model, for instance $dt = 0.01$ s, which is not a problem for contemporary computers (Gucma et al. 2008), but ship's fuzzy control in confined waters requires further analysis.

2 FUZZY LOGIC CONTROLLER

In autonomous FTS the manoeuvring decision finding can follow the procedure described in Zalewski (2003). However if any of the present ship state vector parameters comes outside the scope of the expert database it is assumed that the optimum manoeuvre should lead the ship to regain safe values of state vector parameters. For this purpose the fuzzy discrete-time controller can be designed. The major components of the typical fuzzy controller are fuzzification, fuzzy rule base, fuzzy inference, and defuzzification. These components will be described further in an exemplary MISO (multiple input single output) controller of pitch for vessels with two propellers.

2.1 *Fuzzification*

Fuzzification is a mathematical procedure for converting an element in the universe of discourse into the membership value of the fuzzy set.

In the Figure 1 controller output is designated by $u(n)$ and system output is designated by $y(n)$, where n

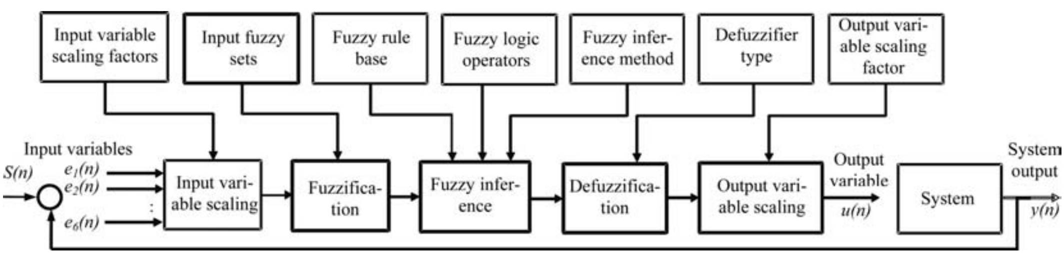

Figure 1. Structure of a MISO fuzzy control system which is composed of a Mamdani fuzzy logic controller and a system under control (based on Ying (2000)).

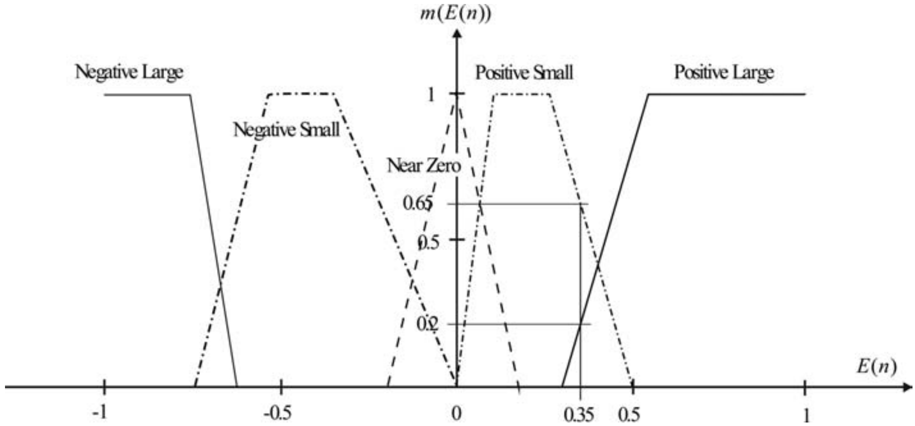

Figure 2. Illustration of the Δv_x input variable fuzzification.

is a positive integer representing sampling time dt. The desired system output trajectory is denoted as $S(n)$.

In case of system being a ship, steered in accordance to expert passage, $u(n)$ will be pitches setting, $y(n)$ will be a vector containing six variables defining actual motion in 3-degrees of freedom: P_{xy} – actual position of selected waterline point stored as two variables, v_x – actual longitudinal (advance) velocity, v_y – actual transverse (lateral) velocity, ω – actual angular (rotation) velocity, ψ – actual ship's heading; and $S(n)$ will be a vector containing six variables defining required motion in 3-dof: P_{xyr} – required position of selected waterline point stored as two variables, v_{xr} – required advance velocity, v_{yr} – required lateral velocity, ω_r – required rotation velocity, ψ_r – required ship's heading At time n, $y(n)$ and $S(n)$ are used to compute the input variables of the fuzzy controller (effect of pitches setting on motion): ΔP_{xy} – deviation between required and actual position, Δv_x – difference or deviation between required and actual longitudinal (advance) velocity, Δv_y – difference or deviation between required and actual transverse (lateral) velocity, $\Delta\omega$ – difference or deviation between required and actual angular (rotation) velocity, $\Delta\psi$ – difference or deviation between required and actual ship's heading. So generally the input variables vector can be designated by:

$$e(n) = S(n) - y(n) \tag{1}$$

Input variable scaling factors are used to conveniently manipulate the effective fuzzification on the scaled universes of discourse. The scaled factors used for $e(n)$ vector in presented research are normalization constants of the five mentioned deviations, with their preserved positive or negative sign, as accepted in Zalewski (2003). Assuming the scaling factors for deviations as vector K_e the scaled input vector is:

$$E(n) = K_e e(n) \tag{2}$$

The scaled variables are then fuzzified by input fuzzy sets defined on the scaled universes of discourse: [0,1]. Figure 2 shows five input fuzzy sets for one of the $E(n)$ parameters that are used by the fuzzy controller. At this conceptual phase of FTS model development the research on the most suitable fuzzy sets is still ongoing so the most popular membership functions types found in literature have been selected, namely triangular and trapezoidal.

The fuzzification results for normalized Δv_x value of $E(n)$, $E_2(n) = K_{e2} \times \Delta v_x$, shown in Figure 2, are membership value of 0.65 for fuzzy set Positive Small (PS) and 0.2 for fuzzy set Positive Large (PL). The linguistic names "Positive" and "Negative" are related directly to faster advance speed than required and slower advance speed than required respectively. The membership values for Near Zero (NZ), Negative Small (NS) and Negative Large (NL) are 0.

Fuzzification can be formulated mathematically replacing linguistic naming system by a numerical index system, for instance five fuzzy sets used may be represented by A_i, $i = -2$ (NL), -1 (NS), 0 (NZ), 1 (PS), 2 (PL). The example fuzzification of $e_2(n)$ with $K_{e2} = 0.7$ s/m at time t: $e_2(n) = \Delta v_x = 0.5$ m/s, $E_2(n) = 0.35$ can be described as:

$$m_{A_{-2}}(e_2(n)) = 0 \tag{3}$$

$$m_{A_{-1}}(e_2(n)) = 0 \tag{4}$$

$$m_{A_0}(e_2(n)) = 0 \tag{5}$$

$$m_{A_1}(e_2(n)) = 0.65 \tag{6}$$

$$m_{A_2}(e_2(n)) = 0.2 \tag{7}$$

No mathematically rigorous formulas or procedures exist to accomplish the design of input fuzzy sets – the proper determination of design parameters is strictly dependent on the experience with system behaviour, hence the expert data coming from ship manoeuvring trials is necessary.

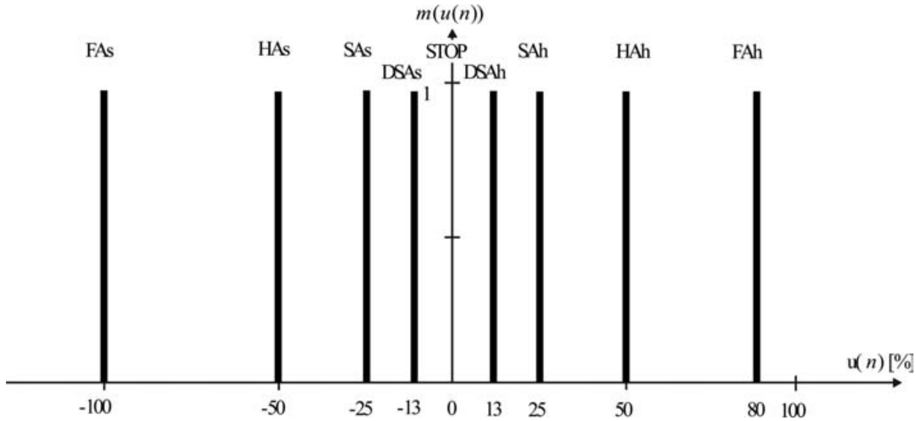

Figure 3. Singleton fuzzy sets as output fuzzy sets in the designed controller.

2.2 *Fuzzy rules*

Fuzzification results are used by fuzzy logic AND operations in the antecedent of fuzzy rules to make combined membership values for fuzzy inference. An example of a Mamdani fuzzy rule used for control of simulated ship advance speed is:

IF $E_2(n)$ is PL AND $E_1(n)$ is NS
THEN $u(n)$ is SAs (8)

where PL and NS are input fuzzy sets and SAs (Slow Astern) is an output fuzzy set. In essence rule (8) states that if ship's advance speed is significantly larger than the desired advance speed and the ship's position is a little back of the desired one (calculation of vector connecting both positions must be done) the controller output should be the pitch setting corresponding to Slow Astern fuzzy set.

The quantity, linguistic names, and membership functions of output fuzzy sets are all design parameters determined by the controller developer. Similarly to input fuzzy sets the most popular membership functions of singleton type have been used (Fig. 3).

The exact number of fuzzy rules is determined by the number of input fuzzy sets. For the considered system of ship control the total number of fuzzy rules will be the combination of 5 input variables and 5 fuzzy sets (if for all variables the same number of fuzzy input sets is designed): $5^5 = 3125$; quite a large amount for only pitches setting. Actually this number of fuzzy rules can be significantly reduced by treating each input variable independently and combining the output during defuzzification. This can be achieved by utilizing coupled fuzzy controllers.

2.3 *Fuzzy inference*

The resultant membership values of input sets produced by fuzzy logic AND operation (Zadeh or product operator can be used (Ying, 2000)) are then related to the singleton output fuzzy sets by fuzzy inference. The four common inference methods produce the same inference result if the output fuzzy set is singleton. Assuming that for fuzzy sets A_i membership values are given by (3)–(7), and for fuzzy sets B_i, corresponding to position deviation, the membership values are:

$$m_{B_{-1}}(e_1(n)) = 0.5 \tag{9}$$

$$m_{B_0}(e_1(n)) = 0.3 \tag{10}$$

if four fuzzy rules similar to (8) will be activated at time n, using the Zadeh fuzzy logic AND operator and Mamdani minimum inference method (Ying 2000) yields the following inference results:

for $u_1(n) = $ DSAs (Dead Slow Astern):

$$m_{Z_1} = \min(m_{A_1}(e_2(n)), m_{B_{-1}}(e_1(n))) = \\ = \min(0.65, 0.5) = 0.5 \tag{11}$$

for $u_2(n) = $ STOP:

$$m_{Z_2} = \min(m_{A_1}(e_2(n)), m_{B_0}(e_1(n))) = \\ = \min(0.65, 0.3) = 0.3 \tag{12}$$

for $u_3(n) = $ SAs (Slow Astern):

$$m_{Z_3} = \min(m_{A_2}(e_2(n)), m_{B_{-1}}(e_1(n))) = \\ = \min(0.2, 0.5) = 0.2 \tag{13}$$

for $u_4(n) = $ HAs (Half Astern):

$$m_{Z_4} = \min(m_{A_2}(e_2(n)), m_{B_0}(e_1(n))) = \\ = \min(0.2, 0.3) = 0.2 \tag{14}$$

If output fuzzy sets in rules are the same fuzzy logic OR operation can be used to combine the memberships. In the presented example all four output singleton sets are different (DSAs, STOP, SAs, HAs) so the calculation will continue without it.

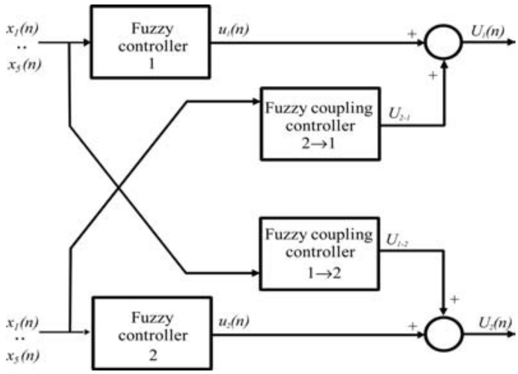

Figure 4. MIMO coupled fuzzy controller.

2.4 *Defuzzification*

The membership values computed in fuzzy inference must be finally converted into one number by a defuzzifier. In the ongoing research the most prevalent defuzzifier in literature – centroid defuzzifier has been used (Piegat 2003, Ying 2000). In the presented example the defuzzifier output at time *n* is:

$$u(n) = \frac{m_{Z_1} \cdot u_1 + m_{Z_2} \cdot u_2 + m_{Z_3} \cdot u_3 + m_{Z_4} \cdot u_4}{m_{Z_1} + m_{Z_2} + m_{Z_3} + m_{Z_4}} \tag{14}$$

where:
$u_1 = -13\%$ of pitch/throttle position (DSAs),
$u_2 = 0\%$ of pitch/throttle position (STOP),
$u_3 = -25\%$ of pitch/throttle position (SAs),
$u_4 = -50\%$ of pitch/throttle position (HAs),
so $u(n) = -18\%$ of pitch/throttle position.

$u(n)$ is the new output of the fuzzy controller at time *n* which will be applied to the ship system to achieve control. In comparison with conventional controllers, what is lacking is the explicit structure of the fuzzy controller behind the presented procedure. On the other hand utilizing expert knowledge for such a black box is much more straightforward and comprehensive.

3 MIMO SYSTEM

The controller's design process is further complicated by its multidimensional output. The possible solution of this problem has been presented in [6] by utilizing coupled controllers. Also usage of independent fuzzy controllers in the control of a MIMO system (multiple input, multiple output) can give good results.

Figure 4 presents exemplary structure of a coupled fuzzy controller for 5 input variables and 2 output variables (pitch settings of both propellers). Each controller utilizes its own fuzzy sets membership functions and fuzzy rules covering impact of pitches settings on the rotation and lateral speed of the vessel.

4 CONCLUSIONS

The human shiphandling expertise and knowledge can be captured and utilized in the form of fuzzy sets, fuzzy logic and fuzzy rules. The expertise and knowledge are actually nonlinear structures of physical systems which are represented in an implicit and linguistic form rather than an explicit and analytical form, as dealt with by the conventional system modeling methodology. That is why fuzzy controllers can be suitably implemented into nonlinear dynamic model of ship control. Fast time simulation based on such model should give satisfactory results even after logging only one or few expert passages in relevant area and conditions. Afterwards the FTS model can run autonomously provided that the proper ship safety limits are achieved by designed fuzzification (membership functions) and inference (fuzzy if-then rules and operators) processes.

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2.6
Ship manoeuvring performance experiments using a free running model ship

N. Im & J.-H. Seo
Mokpo National Maritime University, Mokpo, South Korea

ABSTRACT: In this paper, a 3m-class free running model ship will be introduced with its manoeuvring performance experiments. The results of turning circle test and zig-zag test will be explained. The developed system are equipped with GPS, main control computer, wireless LAN, IMU (Inertial Measurement Unit), self-propulsion propeller and driving rudder. Its motion can be controlled by RC (Radio Control) and wireless LAN from land based center. Automatic navigation is also available by pre-programmed algorithm. The trajectory of navigation can be stored by GPS and it provides us with important date for ship's motion control experiments. The results of manoeuvring performance experiment have shown that the developed free running model ship can be used to verify the test of turning circle and zig-zag. For next step, other experimental researches such as ship collision avoidance system and automatic berthing can be considered in the future.

1 INTRODUCTION

Recently many researches on ship automatic navigation system have been carried out. The one of system required for these researches is a free running model ship. A free running model ship has been used in ship model basin area to validify or confirm ship's manoeuvring/motion or resistance performance before the ship's building. When a free running model ship is used in a basin, usually it is known that there are limits of basin size to fully test the ship's performance. Therefore many researches have been carried out outdoor such as pond or river.

When experiment is conducted outdoor using a free running model ship, a lot of equipments are required such as IMU (Inertial Measurement Unit), GPS (Global Position System) and other facilities to get other ship's information. This paper will introduce MMU (Mokpo National Maritime university) free running model ship which can be used for ship's manoeuvring/motion performance tests. The system is equipped with GPS and AIS to get ship's real time position and other ship's information. Main purpose of this model ship is to carry out ship's intelligent navigation test where the ship navigate recommend sea route or ship avoid other ship in the sea without human control automatically. The research in this paper was carried out as the first step of these researches. The structural and functional concept of the free running model will be introduced. We carried out basic ship's performance tests such as tuning circle and zig-zag test as a first step of ship intelligent navigation tests. We found good performance in the model ship and that the model can be utilized in ship intelligent navigation tests in the future.

2 THE STURECTURE OF A FREE RUNNING MODEL SHIP

The MMU free running model ship consists of following equipments.

– Main electric system
– Device control system
– Signal measurement system
– Communication system
– Model ship

2.1 *Main electric system*

A free running model ship usually requires high capacity of power because it is operated open waters with wind disturbances. The electric system of MMU model supplies its electricity to servo motors and computer power and communication system. Two servo motors are equipped in the model ship, one (700W) for propeller and the other (100W) for rudder operation. In operation situations, the servo motors always controlled, so capacity of battery is important to keep the model powered for long time. Two of battery are installed with a 12V deep cycle method and 100ah class of parallel circuits. Output power from batteries is sent to a DC/AC inverter and converted into 220V single-phase current for each electricity equipments. A current transformers or SMPS (Switching Mode Power Supply) of 24V or 12V often is used for small capacities equipments.

2.2 *Device control system*

Control device system consists of access point (IEEE.802 11g), laptop computer, PMAC, servo driver

Figure 1. Battery and converter.

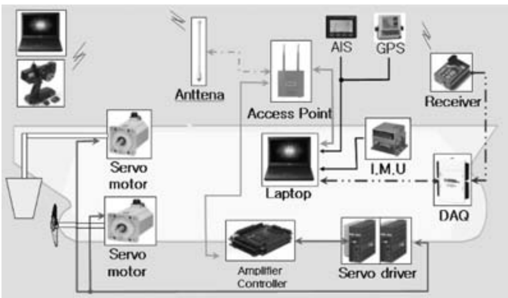

Figure 2. System flow in a model ship.

and wireless control system. The following explains more details

– Laptop computer
  It controls the total system of model ship. Its signal translated into each equipment with TCP/IP signal through a network adopter
– PMAC
  When it receives TCP/IP singal, the output of range 0-10V is produced and sent to each servo driver such as rudder and propeller gears.
– Serve driver
  It controls the rudder and propeller motors with signals from PMAC.
– Radio control Receiver
  The receiver get signals from radio control transmitter to control rudder angle and propeller revolution. The translated signal is sent to laptop computer by way of NI USB-DAQ.

2.3 *Data acquisition system*

The signals in a free running model can be into two types roughly. The first is signal for a ship motion control part and the second is for motion measurements such as 6 DOF (Degree Of Freedom). All signals from ship's motion and control part is translated into laptop computer in the model where each signal are stored or re-translated according to their purpose. The following explain measured signal at each equipment.

– PMAC
  Each phase generated in encoders of servo motor is input into PMAC via servo driver. The input phases are converted into meaningful data for rudder location and propeller revolution. The data also translated into laptop computer via TCP/IP to be stored as data log or monitoring purpose.

Figure 2a. Data acquisition system.

– NI-USB-DAQ
  The data translated into radio control receiver is converted to PWM (pulse Width Modulation) signal. The NI-USB-DAQ translate the signal of PWM into laptop computer in model ship via USB port.
– 6 Axis IMU (Inertial Measurement Unit)
  The signal data from IMU are translated into computer by serial communication. They are used for ship's motion logging and monitoring.
– GPS (Global Position System)
  The signal data from GPS also are translated into computer by serial communication. They are used for logging and monitoring of ship's trajectory.
– AIS (Automatic Identification System)
  It is equipped to obtain other ship's information such as ship's position, heading angle and speed. Its signal also translated as serial data into computer. This system can be used as one of intelligent navigation system. When a model ship avoids collision situations, the data from AIS is very essential to calculate the risk of collision between two ships.

2.4 *Communication system*

A communication system of the model ship can be divided into three types of analogue signal, TCP/IP and RS-232. The following are explanations of equipments and protocol.

– Digital and analogue signal
  Encoders in servo motor produce several pulse. Control signal for servo motor ranges from 0V to 10V. The NI-USB-DAQ adopted in the model ship has spare channel for signal I/O , therefore additional hardware installation will be convenient such as wind and current meters and additional propulsion equipment.
– TCP/IP
  The access point (IEEE. 802.11g), a close range wireless communication protocol, enable users to transmit data with 54Mbps. The communication between the laptop computer in the model ship and shore control center is possible by TCP/IP. The

Table 1. Principal particulars of model ship.

	Ship	Model
Scale ratio	1	100
Design speed	15.5(knots)	0.7973(m)
L.B.P(m)	320	3.2
L.W.L(m)	325.5	3.255
B(m)	58.0	0.58
Depth(m)	30.0	0.3
Draft(m)	20.8	0.2080
m^2WSA()	27320.0	2.7320
m^2Volume()	312737.5	0.3127
C_B	0.8101	0.8101
F_A	0.142	0.142

Table 2. Principal particulars of model ship.

Rudder		Propeller	
Type	Horn	Type	FP
S of rudder(m^2)	273.3	No. of blades	4
Lat area(m^2)	136.7	D(m)	9,86
Turn rate (deg/sec)	2.34	P/D(0.7R)	0.721
		Ae/A0	0.425
		Rotation	C.W
		hub ratio	0.155

Figure 3. The picture of the model ship.

signal to/from PMAC is translated via access point with form of TCP/IP to control ship's operation.

– RS 232
Several equipments such as IMU, AIS and GPS use serial data transmission, RS 232. All data from these equipments are stored in laptop computer system for logging and monitoring of the ship's situations.

– PWM (Pulse Width Modulation)
Emergency situations such as model ship power failure or collisions require prompt and direct control. Radio control transmitter- receiver deals their signal with PWM method. When NI-USB-DAQ receives pulse from radio control receiver and decides what kinds of control should be done using the pulse's time from raising edge to falling edge.

Table 3. Opeating System of Software

Computer OS	Widows XP
Computer Language	LabVIEW 8.5
device driver	PMAC
	NI-DAQ

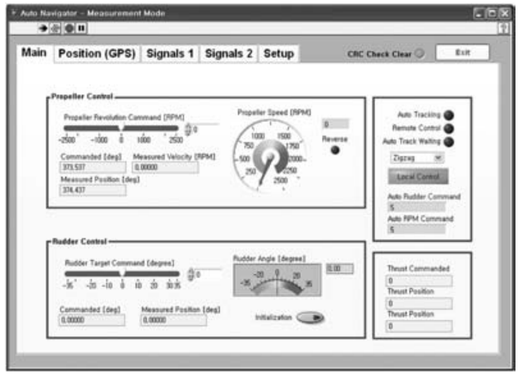

Figure 4. Main screen of operating program.

2.5 *Model ship*

The model ship has 1/100 of model scale. Water-proof was considered in every hatch to prevent capsizing of the model. The table 1 and 2 show the principal of model ship. The figure 2 explains the model ship.

3 THE MODEL OPERATION

The operating system for the model ship can be divided into two system of software operating system and hardware operating system.

3.1 *Operating system of software*

Table 3 indicates software operating system adopted for the model ship. As shown this table, Window XP and LabView are used for OS and computer program language.

3.2 *Operating system of hardware*

Critical control is done by inner computer on board which is controlled from shore computer with wireless network communication. A priority of control is set to radio control receiver-transmitter in specified frequency to cope with emergency situations. This enables users to take appropriate and prompt actions. In case of radio control receiver failure or networks signal errors, the inner computer of model ship is designed to run programmed sequence or process. The figure 4 indicates the priority of operation system. When local control mode is selected, model ship can be controlled by shore or inner laptop computer by manual mode. If local control mode is cancelled, radio

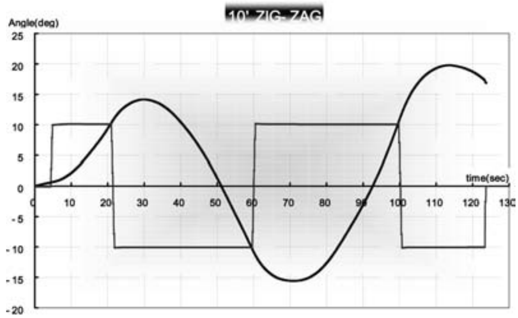

Figure 5. 10-10 zig-zag test in towing tank.

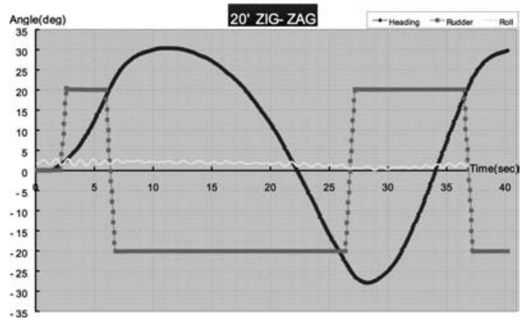

Figure 6. 20-20 zig-zag test in the sea.

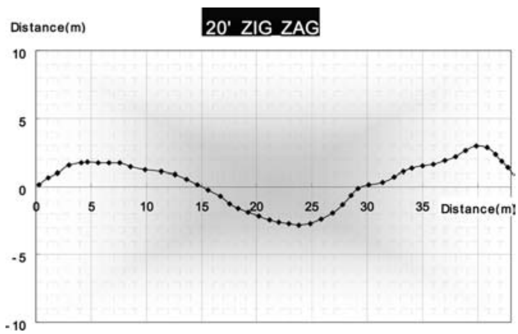

Figure 7. Ship's trajectories in 20-20 zig-zag test.

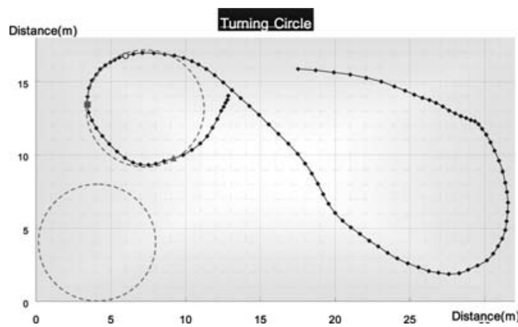

Figure 8. Ship's trajectories in turning test.

control is searched at first. When radio control signal is not found, automatic navigation control mode is activated.

Users can use additional safety measurement, the function of "fail safe" where radio control system can be kept specified conditions or stopped if radio transmitter-receiver failed to get signals or the level of power in battery is so low. This enables the user to cope with emergency situations such as power failure in model ship or critical collision situation.

All data of model ship can be obtained from USB ports. Additional equipment's installation also is possible through spare ports of USB.

4 EXPERIMENTS

In this research, two kinds of experiments are carried out in the costal sea and in a towing tank. Zig-zag test and turning test were performed. These tests are known as very essential and important method to evaluate a ship's manoeuvring performances.

4.1 *Zig-zag test*

Zig-zag test of 10-10degree and 20-20degree were performed. The figure 5 shows the results of 10-10zig-zag test carried out in towing tank. The figure 6 shows the results of 20-20 zig-zag test carried out in the costal sea side. As shown in these figures, it is found that the model ship well perform zig-zag test without any errors and the data of ship's heading and rudder angle also are very clear.

Figure 7 shows the ship's trajectories obtained by GPS during ship's zig-zag test.

4.2 *Turning circle test*

Ship's turning test also was carried out. A turning circle tests usually to be performed to both starboard and port with 35 degree rudder angle. The rudder angle is executed following a steady approach with zero yaw rate. Figure 8 and 9 show the results of turning test. As shown in these figure, the trajectories of the model and ship's heading and rudder angle are clearly obtained to evaluate ship's manoeuvring performances. The diameters of tactical and advance are found around 7-8 meters. This experiment was performed in open sea. Environmental disturbances such as wind and current effects are included into the results of the experiment.

5 CONCULSIONS

The main points of research can be summarized as followings.

- The main structure and concept of MMU free running model ship were introduced.
- Zig-zag tests and turning tests were performed to evaluate the model ship's essential usefullness.

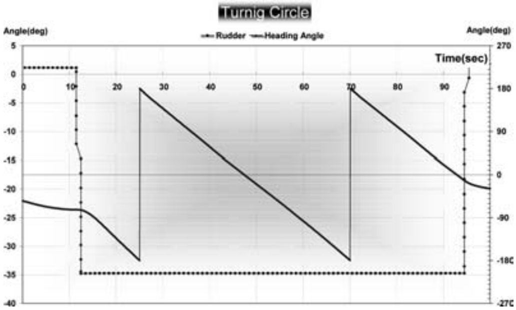

Figure 9. Ship's data in turning test.

Figure 10. Zig-zag test in towing tank.

– It was found that the model ship's software and hardware system were enough to be used further ship's control research in the future such as ship's intelligent control fields.

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2.7 Simulation of load distribution along a quay during unparallel berthing manoeuvres

J. Artyszuk
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: The marine berths are normally secured for safety reasons with a system of fenders. Their role is to absorb and dissipate the kinetic energy of a ship coming into a contact with a berth, so the structural integrity of both the berth and ship's hull is preserved. Normally the combination of a number and the single fender strength indicate the ship's maximum allowable lateral speed in parallel berthing conditions (of course, with a safety margin frequently taken into account). More or less directly and/or approximately, this is also a general selection method for fender systems. The main objective of this conference contribution, as inspired by some suggestions and needs within a domestic marine society since the author's developed and successfully implemented fender effect in ship manoeuvring simulation, is to analyse the local loads in a particular fender around the region of contact during an oblique berthing. Various conditions of ship's lateral and angular velocities are tested. The results are compared with some practical shiphandling tips, as to be found in the literature, leading to a necessity of revision of the existing practice. The presented investigations are believed to be very helpful also for fender system designers.

1 INTRODUCTION AND OBJECTIVES

Deck officers simplify the problem of ship berthing, whether made on her own or with tugs assistance, to maintain proper local lateral velocities fore (at the bow) and aft (at the stern). Both movements are able to be measured by an onboard doppler log (with sensors in the mentioned locations), an onboard docking system (as the satellite-based one with two antennas, or where the linear velocity vector, e.g. from a satellite system, is integrated with the rate of turn from a gyroscopic sensor, or in which inertial sensors are finally applied), or a docking system ashore, if applicable. Some terminals report a maximum allowable lateral approach speed for various weather conditions and ship sizes. By default, the essentially parallel approach is therein assumed.

Of course, this practice really works when an attempt is made to restrict these velocities as close as possible to zero. However, some major or minor problems can happen if the bow and stern velocities are significantly non-zero, different from each other, or occurring at the ship's non-zero direction angle to a berth (thus making a 'single point' contact).

In the following a closer look into the ship-berth (or ship-fender) interaction phenomenon is intended, because the situation is more complex, as usual, in the real-world. The local loads in fenders and absorbed energies will be studied in detail. The problem is tackled by the comprehensive ship manoeuvring simulation with a full control over the fender effects. According to the author's opinion the existing full-mission ship-handling bridge simulators do not allow any analysis of loads in fenders, except for sending a 'broken fender' alert. Moreover, the implemented fender dynamic effect on ship manoeuvring motions is often not well modelled.

2 SIMULATION EXPERIMENTS

The designed simulation experiment consists of a manoeuvring mathematical model of small chemical tanker 6000 DWT. The ship data as of direct interest in berthing problems are briefed in Table 1. Other hydrodynamic features of the model can be found e.g. in (Artyszuk, 2005). The model runs within the fast- and real-time interactive ship manoeuvring simulation software SMART (all the mechanical effects included) as developed by the Author. As to properly evaluate the fender forces the integration and recording time step 0.05 s is adopted on the basis of some preliminary convergence simulation trials with the berthing manoeuvres in concern.

For reference purposes the deep water conditions near the berth are selected, since there is a significant scatter in the literature concerning the shallow water correction factors for added masses and hull hydrodynamic forces. The patterns of local loads in the fendering system in such circumstances are however believed to be very similar to those of deep water case, of course except for absolute values. Because the fender reaction forces really dominate when a contact with fenders is already established (even before or after that moment the hydrodynamic damping forces are too small to change the ship very slow motions in

Table 1. The ship basic data.

Symbol	Value	Name
m[t]	8948	displacement (mass)
L[m]	97.4	length between perpendiculars
B[m]	16.6	breadth
T[m]	7.1	draught
k_{11}[-]	0.056	surge added mass coeff.
k_{22}[-]	1.004	sway added mass coeff.
k_{66}[-]	0.83	yaw added inertia coeff.
r_z[-]	0.2465	ship's gyration radius (length units)

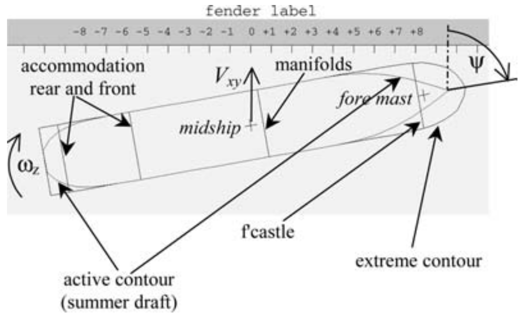

Figure 1. Situational sketch of portside berthing manoeuvre.

a rather short time period) the most important for the shallow water berthing simulation is the augmentation of added masses. Nevertheless, some characteristic shallow water aspects will be later raised in the study.

Furthermore, the model of discretely spaced linear fenders, as described in (Artyszuk, 2003), is used in the research – the fender reaction increases proportionally to its compression while for decompression it practically disappears. Though the SMART environment is capable of implementing any nonlinear load-deflection chart of the fender (including the so-called hysteresis), the adopted linear characteristics enables a direct comparison of simulation results with those obtained by the analytical dynamic method for a single fender. The latter analytical approach, based on a set of linear ODEs, was introduced in (Artyszuk, 2003). In view of the current concern more results of this analytical method are contained in Table 4. The analytical method is universal in such a way that after some minor extensions it gives ship movements after the impact for any initial condition in terms of the direction angle, linear and angular velocities. This certainly could help to solve a dispute in the domestic literature (Magda, 2006) with regard to the Vasco Costa formula (Vasco Costa, 1964) for the berthing energy absorption, as based on the angular momentum conservation theory for non-elastic collisions.

A berth secured with 20 fenders (each of the maximum force 100 t at the deflection 20 cm that contributes to the energy absorption $E_F = 98.1$ kJ per single fender) is set up from the practical viewpoint. As opposed to (Artyszuk, 2003, 2005), in the present research the linear reaction of a fender during the decompression phase is additionally assumed, though set only at the level of 1% of the compression-related reaction at the same deflection. These fenders are spaced every 5 m that corresponds to 1/20 of the ship's length, since trials with 10 fenders, arranged every $0.1\,L$, have failed in this sense that safe berthing speed under such circumstances is relatively low (even in deep water constituting the most favorable berthing conditions). It shall be here namely emphasized that the usual curvature of the ship's waterline contour (specifically the length of ship's parallel body), see Figure 1, leads in our case to the compression of just 11 to 13 fenders (of the total number 20) depending on the lateral speed. These are 6(7) aft, 1 center, and 4(5) forward fenders for the speed 0.3(0.6) kt.

Table 2. Summary of simulation runs.

Symbol	Heading	Mode of Motion v_y (sway)	/	ω_z(yaw)
R0.	090°	neg.	/	–
R1.	090°	neg.	/	–
A0.	088°	neg.	/	–
B0.	085°	neg.	/	–
C0.	080°	neg.	/	–
D0.	075°	neg.	/	–
E0.	070°	neg.	/	–
F0.	060°	neg.	/	–
B1.	085°	–	/	neg.
B2.	085°	pos.	/	neg.
B3.	085°	neg.	/	pos.
G0.	095°	neg.	/	–
G1.	095°	–	/	pos.
G2.	095°	pos.	/	pos.
G3.	095°	neg.	/	neg.

All the fenders are labeled according to their relative location against the ship's midship section (Fig. 1). There are 15 runs considered in the experiment, in which the ship after an initial excitation moves by inertia towards the berth – see Table 2.

The first two runs (R0, R1) deal with a parallel approach at different lateral velocity (0.3 m/s and 0.15 m/s correspondingly). The other six in order (A0 ÷ E0) constitute an oblique, constant heading bow-in (bow-first) berthing at a different ship-to-berth direction (starting from 2° up to 30°), in which the linear velocity $v_{xy} = 0.15$ m/s (0.3 kt) is kept normal to the berth. Such a condition means the varying forward and lateral (negative to portside) velocities, v_x and v_y, according to the projections of total velocity vector in ship's body axes – see the first row of Table 4a. The consecutive three runs (B1 ÷ B3) take a focus on a possible different combination of the linear and angular (positive to starboard) velocity as to arrive at the same local lateral velocity (equal to 0.15 m/s) for the ship's hull point of the first contact. In the bow-in berthing the latter lies approximately at the one quarter of the

Table 3. Motions and energy absorption – analytical study.

	Fender abscissa (in ship's length from amidships)					
	0.0	***+0.1***	***+0.2***	***+0.3***	***+0.4***	***+0.5***
t_{max} [s]	3.0	2.8	2.3	1.9	1.5	1.3
v_{y1} [m/s]	0.0000	−0.0382	−0.1047	−0.1547	−0.1856	−0.2046
ω_{z1} [°/min]	0.00	13.47	18.48	18.19	16.38	14.44
$\%E_1(\omega_z)$	0.00	0.85	0.58	0.38	0.26	0.18
E_1 [kJ]	0	86	235	347	416	459
dE_1 [kJ]	560	475	326	214	144	102
$\%dE_1$	1.00	0.85	0.58	0.38	0.26	0.18
dE_1/E_F	5.7	4.8	3.3	2.2	1.5	1.0

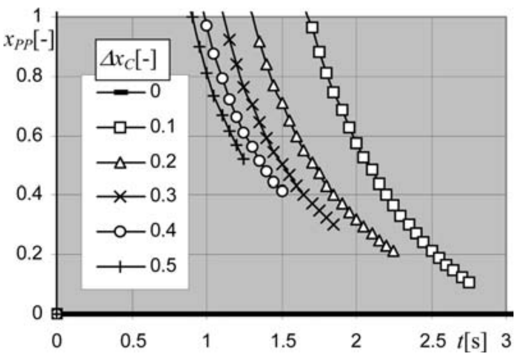

Figure 2. Ship's pivot point during the work of fender.

ship's length (∼25 m) from the amidships position. The last four manoeuvres (G0 ÷ G3) comprise some cases of the stern-in berthing at 5° to the berth. The varying combination of lateral and yaw velocities also contributes to the local contact velocity of order 0.15 m/s, which is however now connected with the hull point placed 40 m astern from the ship's midship.

3 ANALYSIS OF RESULTS

As aforementioned, of a great assistance in physical explaining and/or verifying the simulation results appears an application of the analytical method – see the following Table 3. If a ship moving nearly perpendicularly to the berth hits a single fender, the resulting after the impact lateral v_{y1} and yaw ω_{z1} velocities generally depend on the fender contact point in relation to the ship's midship (index '1' denotes the first impact, here the bow impact, '2' refers to the second impact i.e. by the stern). To be more precise one should refer the fender position to the ship's radius of gyration r_z – see also the early works of Vasco Costa (Vasco Costa, 1964, 1968). The instant pivot point position x_{PP} during the fender compression decreases from the infinity up to the convergence with the fender position Δx_c at the moment of maximum deflection t_{max}. For the chemical tanker in concern with a berthing speed of 0.25 m/s this is presented in Figure 2, where both magnitudes are expressed in units of the ship's length (the value +0.5 coincides with the ship's bow).

It is evident from Table 3 that the highest contribution to the residual total kinetic energy after the first impact, as actually coming from the ship's rotation, is gained for a fender close to the midship section – the parameter $\%E_1(\omega_z)$ represents the ratio of yaw-related energy to the total remaining energy E_1. The difference between E_1 and the initial energy E_0(here arising from the pure lateral motion) is represented by dE_1. Furthermore, the quantity $\%dE_1$ means the ratio of just absorbed energy dE_1 to the initial energy E_0, while the expression dE_1/E_F indicates the absorbed energy as compared to the fender specific maximum energy E_F that can be safely absorbed (here $E_F = 98.1$ kJ). Values of dE_1/E_F in Table 3 higher than unity, specifically for fenders close to the midship, are rather theoretical ones (although of some practical implication), since the assumed linear fender was allowed to be compressed outside the limit of 20 cm, which was necessary to completely stop the ship and transfer her full kinetic energy to the fender. It must be well understood that for the mostly forward fenders the absorbed energy is essentially lower, but the rest of initial energy still remains on the ship and increases the risk of second impact.

The ship's kinematic behaviour during berthing as experienced within the scope of the simulation experiment (see Section 2) is summarised in Table 4a and 4b, except for the run R0 that is similar to R1 in output. The subscripts '0' and '1' relate to the condition before and after the first impact, the indices '2' and '3' deal with the second impact accordingly (if applicable). Time t_2 is the moment of beginning the second impact as counted from the start of the first impact. The parameter dE_3 stores the released (absorbed) energy during the second impact. Though the first impact in the bow-in berthing can affect up to maximum three particular forward fenders, see the last row in Tables 4a and 4b, the second impact is somehow a continuous pressing of all fenders in sequence (strictly related to the hull parallel body), as installed on the berth, commencing from the fenders of the first impact. In this context t_2 indicates the point of time when the ship activates the first aft (negative) fender, see Figure 1. The meaning

Table 4a. Motions and energy absorption – simulation.

	Run no.						
	R1	***A0***	***B0***	***C0***	***D0***	***E0***	***F0***
v_{y0} [m/s]	− 0.1475	−0.1460	−0.1433	−0.1409	−0.1386	−0.1313	−0.1232
ω_{z0} [°/min]	0.00	0.03	0.13	0.33	0.44	0.84	0.83
$\%E_0(\omega_z)$	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_0 [kJ]	195	191	185	181	179	167	162
v_{y1} [m/s]	0.0167	−0.0631	−0.0693	−0.0802	−0.0871	−0.0883	−0.0938
ω_{z1} [°/min]	−2.43	11.86	11.66	11.11	10.74	10.37	9.54
$\%E_1(\omega_z)$	0.49	0.61	0.56	0.46	0.40	0.38	0.29
E_1 [kJ]	5	92	97	107	114	113	124
dE_1 [kJ]	190	99	88	74	65	54	39
$\%dE_1$	0.98	0.52	0.47	0.41	0.36	0.32	0.24
dE_1/E_F	1.94	1.01	0.89	0.76	0.67	0.55	0.39
t_2 [s]	–	11	28	62	100	146	255
v_{y2} [m/s]	–	−0.0505	−0.0597	−0.0406	−0.0366	−0.0303	−0.0268
ω_{z2} [°/min]	–	11.99	10.06	9.78	8.72	7.61	5.93
$\%E_2(\omega_z)$	–	0.72	0.56	0.72	0.72	0.74	0.69
E_2[kJ]	–	80	72	53	42	31	20
v_{y3} [m/s]	–	0.0287	0.0252	0.0273	0.0241	0.0213	0.0159
ω_{z3}[°/min]	–	2.71	1.69	2.65	2.43	2.08	1.70
$\%E_3(\omega_z)$	–	0.28	0.17	0.30	0.31	0.30	0.34
E_3 [kJ]	–	10	7	9	8	6	3
dE_3 [kJ]	–	70	66	43	35	26	17
% dE_3	–	0.87	0.91	0.82	0.82	0.82	0.83
dE_3/E_F	–	0.71	0.67	0.44	0.35	0.26	0.17
fenders of 1st impact	from −6 to +4	+3, +4, +5	+4, +5	+5, +6	+6	+ 6, +7	+8

Table 4b. Motions and energy absorption – simulation.

	Run no.						
	B1	***B2***	***B3***	***G0***	***G1***	***G2***	***G3***
v_{y0} [m/s]	0.0000	0.1464	−0.2471	−0.1475	0.0000	0.1485	−0.2486
ω_{z0} [°/min]	−20.13	−39.25	13.53	−0.04	12.77	25.30	−8.54
$\%E_0(\omega_z)$	1.00	0.76	0.12	0.00	1.00	0.56	0.05
E_0 [kJ]	162	807	621	195	65	453	583
v_{y1} [m/s]	0.0671	0.2089	−0.1546	−0.1077	0.0357	0.1828	−0.2010
ω_{z1} [°/min]	−8.71	−24.76	26.28	−10.31	3.31	15.21	−19.53
$\%E_1(\omega_z)$	0.43	0.38	0.56	0.29	0.28	0.24	0.30
E_1 [kJ]	71	636	490	146	16	392	515
dE_1 [kJ]	91	171	130	49	49	61	69
$\%dE_1$	0.56	0.21	0.21	0.25	0.76	0.14	0.12
dE_1/E_F	0.93	1.75	1.33	0.50	0.50	0.63	0.70
t_2 [s]	–	-	11	31	-	-	16
v_{y2} [m/s]	–	–	– 0.1095	−0.0787	–	–	–0.1546
ω_{z2} [°/min]	–	–	25.41	−11.25	–	–	–20.60
$\%E_2(\omega_z)$	–	–	0.71	0.48	–	–	0.44
E_2[kJ]	–	–	365	106	–	–	384
v_{y3} [m/s]	–	–	0.0663	0.0311	–	–	0.0584
ω_{z3}[° /min]	–	–	5.57	−5.02	–	–	−7.75
$\%E_3(\omega_z)$	–	–	0.24	0.54	–	–	0.44
E_3 [kJ]	–	–	52	19	–	–	55
dE_3 [kJ]	–	–	314	87	–	–	329
% dE_3	–	–	0.86	0.82	–	–	0.86
dE_3/E_F	–	–	3.20	0.89	–	–	3.36
fenders of 1st impact	+5	+5, +6	+4, +5	−8	−8	−8	−7, −8

of other symbols in both Tables is identical to that of Table 3.

The second impact, though very important in certain circumstances, has received in the literature rather less interest so far. (Vasco Costa, 1964, 1968, 1987) gives only some general shiphandling conclusions, probably due to the lack of appropriate simulations tools to perform such a research.

As shown in Table 4a, the higher angles of approaching the berth, while maintaining the same normal velocity, lead to significant drops in the energy dE_1 absorbed by fenders and rotation-related contribution $\%E_1(\omega_z)$ to the remaining energy. Also proportionally lower energy is absorbed within the second impact, see dE_3. The latter is always weaker than the first impact – the hydrodynamic damping of hull motions during a period till the ship is finally reaching the alongside position seems to be responsible for that.

However, when it comes to fender loads the situation is somehow indefinite – dependent on the number of fenders in contact with the ship's hull, the maximum loads (kN) experienced in fenders are approximately as follows: 790(420), 940(400), 680(350), 800(300), 530(280), 620(210) for runs A0 $\div$ E0 correspondingly. The first value regards forward fenders during the first impact, while a value in parenthesis refers to aft fenders in the second impact. Some of the these results will be supported later with figures. With reference to the less dangerous second impact similar but only qualitative issues have been known in the literature.

It is worthwhile to report that in all the runs the ship, though keeping its almost parallel position very close to the berth, is unnoticeably and slowly losing the contact with fenders that can be called a slight rebound. It also happens in the parallel approach R1. This effect, basically recognizable by the positive lateral velocity v_{y3} after the second impact (or v_{y1} if only the first impact exists), is surprisingly mostly produced by the implementation of the decompression reaction, though very small as mentioned before. The ship's parallel body over its full length namely collects reactions from a number of fenders that give pretty high force in the aggregate. The induced yaw motion in the berthing R1 is due to the asymmetry of fenders around the midship as simultaneously acting on the ship's parallel body.

It is very interesting that for runs B1 and B2, see Table 4b, dealing with the negative yaw velocity (i.e. turning the bow towards the berth), there is no second impact and the ship leaves the berth with 45% and 80% of the initial energy accordingly. Anyhow in the case of B3 simulation (positive angular movement i.e. the bow tends out of berth) the stern impact in terms of the energy is almost 2.5 times stronger than the bow impact. This is an essential quantitative improvement over the Vasco Costa guidance.

The stronger second impact, as compared with the first one, also arises for the stern-in berthing in variants G0 (a constant heading, oblique approach) and G3 if we are of course considering the energy.

It shall be underlined that the second impact measurement in terms of the absorbed energy is not a reliable and comprehensive indication of the ship-berth interaction, since the number of activated fenders is often unknown if they are continuously (close to each other) distributed along the berth. This is partially shown in subsequent Figures 3–5 where the maximum value 1×10^6 N at the scale of vertical axis F_{FND}, representing the fender reaction, is nearly the breaking strength of the fender. The general pattern of fender loads in the time domain as presented agrees with the investigations of (Fontijn, 1988).

For the aforementioned run B3 (Fig. 4) the very high reactions in the aft fenders are really very similar in magnitude to those of the first (bow) impact – both take about 90% of the breaking strength, however the stern impact involves quite a large number of fenders that allows to essentially 'resist' the second impact. Moreover, the nearly twice higher absorbed energy in the second impact is even accompanied by 50% reduction of fender loads. Additionally, the five times higher energy of the second impact in run G3 (here made by the bow), Fig. 5, is just connected with 50% increase of the fender load, though in our particular case the latter assumes nearly breaking value.

The maximum lateral speed for parallel berthing in deep water is the speed of run R0, see also Table 4a, that is equal to 0.3 m/s(0.6 kt). For the assumed fender arrangement this ensures fender loads nearly at the level of their breaking strength. When someone wants to introduce shallow water conditions, the mentioned limit speed is being reduced to 0.52 kt, 0.48 kt, or 0.42 kt if multipliers of order 1.5, 2.0, 3.0 are accordingly applied to the sway added mass. The selected 'reference' velocity for all the peformed simulation runs, see Section 2, at the level of 0.15 m/s just ensures the safe berthing under any tested circumstance i.e. without damage to fenders.

4 FINAL REMARKS

The performed research has proved a great potential of simulating the fender local loads, even in real-time, and demonstrated a ready-for-use software environment serving this purpose.

This study has among others revealed that some meaningful discrepancy between the impact (absorbed) energy and local loads in fenders appears. This shall be taken into account when attempts or efforts are made to establish the best shiphandling guidance with reference to the most favorable combination of lateral (linear) and angular velocity for a given ship, fendering system, depth and weather conditions. Such recommendations, if properly applied, should ease both the first and second impact in terms of local loads. Though the latter is often mitigated by the wheel order.

To quantify the observed rebound phenomenon, that is also of practical importance, further investigations have to be planned, where the fully nonlinear real-world fenders are programmed.

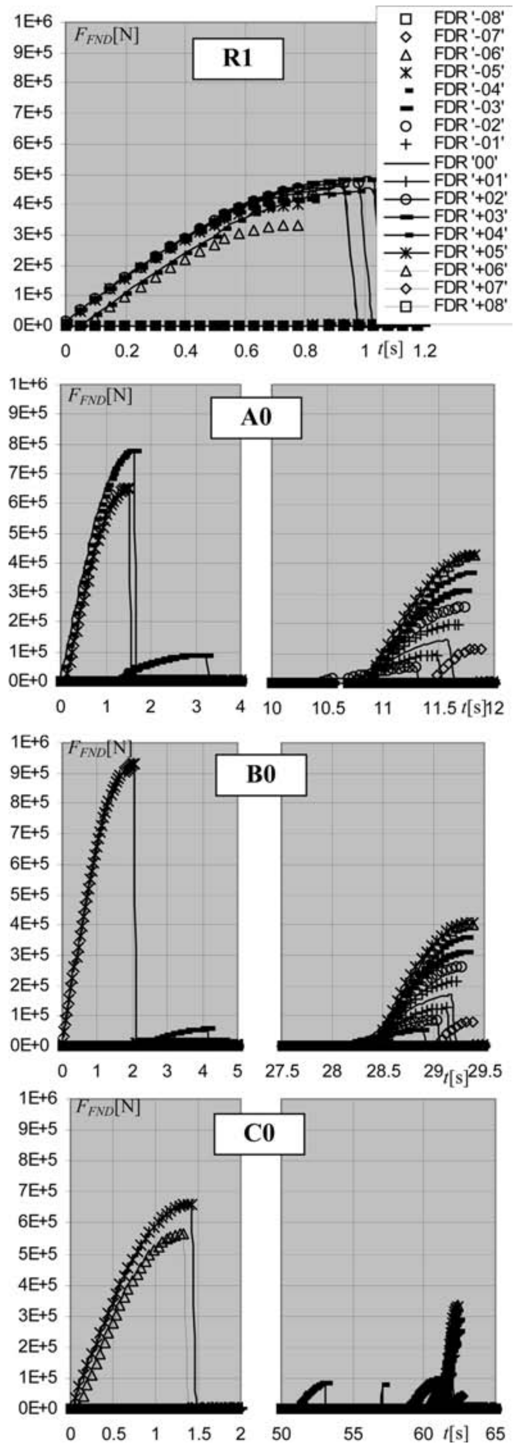

Figure 3. Fender local loads for constant heading parallel and bow-in berthing.

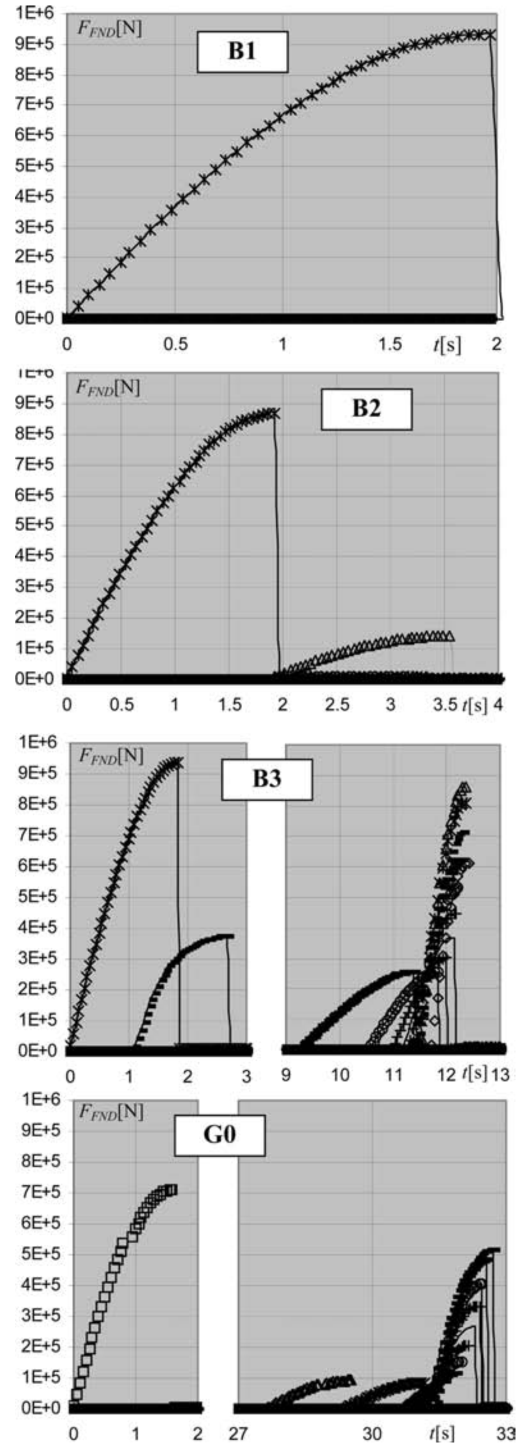

Figure 4. Fender local loads for bow-in berthing with turning and the constant heading stern-in berthing (G0).

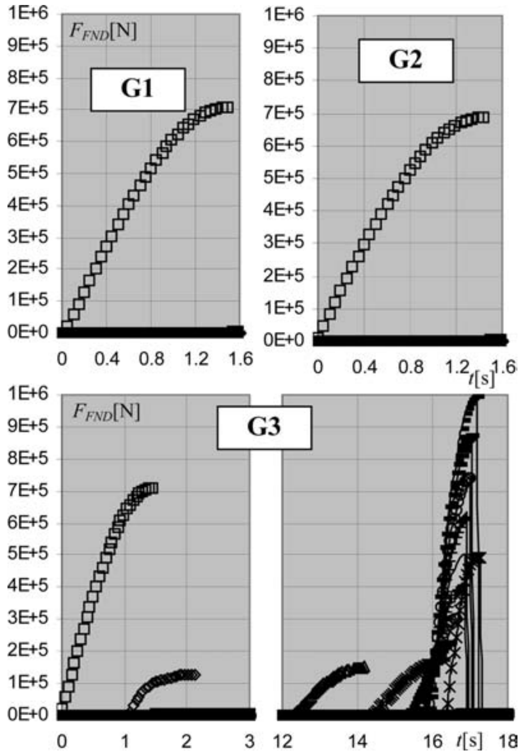

Figure 5. Fender local loads for stern-in berthing with turning.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

2.8 Training course for personnel involved in emergency towing operations

T.E. Berg
MARINTEK – Norwegian Marine Technology Research Institute, Trondheim, Norway

G. Gudmundseth
Ship Manoeuvring Simulator Centre, Trondheim, Norway

U. Klevstad
Norwegian Coastal Administration, Troms and Finnmark Region, Honningsvaag, Norway

ABSTRACT: This paper presents development of and experience from a simulator based training course for personnel in Norwegian emergency response operations. As a response to governmental white papers on emergency preparedness and safety at sea in Norwegian waters, it was decided to develop a simulator based training course with focus on emergency towing operations. The first part of the paper describes work done by a group of subject matter experts appointed by Norwegian Coastal Administration. This group assisted Ship Manoeuvring Simulator Centre to specify the content of a three days training course for deck officers on emergency response vessels. Two test courses were run in the summer of 2006. Feedback from these courses was used to update and extend course content for the first ordinary courses that took place later that year. The second part of the paper reviews course experience and feedback from course participants. The final part of the paper describes the links between the simulator based course and the research and development activities in the R&D project "Arctic Emergency Operation" involving partners from France, Germany, Japan, Norway and United Kingdom.

1 INTRODUCTION

Emergency towing is a high-risk operation. In order to increase the success rate of such operations, specially designed vessels and highly trained crews ought to be employed. However, in most parts of the world, governments are not willing to spend money on dedicated vessels designed to handle worst-case scenarios. Instead, they usually opt for multi-purpose vessels that can perform a number of different tasks under normal operational conditions. For extreme operational conditions such vessels in some cases becomes "multi-useless" vessels, as they are not equipped to handle extreme situations. Nor are crews trained to handle their vessel in these situations, which may increase the risk of unsuccessful outcomes of emergency response operations under the extreme operational conditions that exist in Arctic waters.

A number of relevant papers were presented at a conference in Brest in July 2000. Capt. Charles Claden gives a good presentation of lessons learnt from the Erika disaster. During the discussion Capt. Claden said: "Regarding salvage, emphasis should be given to improved training through more exercises and on better documenting the different emergency towline systems installed on vessels".

Based on experience from emergency towing operations, the International Maritime Organisation (IMO) approved Resolution A535 (13) "Recommendation on Emergency Towing Requirements for Tankers". According to the IMO regulations tankers above 20,000 DWT must be equipped with one strong point at the bow and an emergency towing system (ETS) at the stern. Larger tankers over 150,000 DWT will have 2 strong points and an ETS.

At the 35th meeting of the Maritime Safety Committee (IMO MSC 1994), the guidelines for emergency towing arrangement on tankers were approved. These state that the major components of the towing arrangement should be as listed in Table 1. These requirements are written in a functional form in order to allow for different design solutions. One commonly used design for the strongpoint is the Smit Bracket. Different manufacturers offer different designs, which may create problems in an emergency situation, especially when trying to establish a towing connection for an abandoned ship.

In recent years, the IMO Sub-Committee on Ship Design and Equipment has organized a correspondence group that is looking into the need for similar requirements for other types of vessels larger then 20,000 DWT. In a paper delivered at the 50th session

Table 1. Major components of emergency towing arrangements for tanker.

Component	Forward of ship	Aft of ship	Strength requirements
Pick-up gear	Optional	Yes	No
Towing pennant	Optional	Yes	Yes
Chafing gear	Yes	Depending on design	Yes
Fairlead	Yes	Yes	Yes
Strongpoint	Yes	Yes	Yes
Roller pedestal	Yes	Depending on design	No

of the Sub-Committee in 2006(IMO 2006) it was requested that the Sub-Committee:

– Agree, in principle, to the draft Guidelines for owners/operators on the development of emergency towing procedures as developed by the correspondence group
  The Guidelines have been divided into three main topics:
– Ship evaluation – The evaluation of the vessel's main characteristics (current condition) and available onboard equipment
– Emergency towing booklet (ETB)
– Developing procedures – Guidelines to help create a procedure on how to connect and be towed by another ship in an emergency situation.

INTERTANKO has also recently been working on emergency towing, with a focus on towing lines and their characteristics.

There is well-established collaboration on safety at sea among the Bonn Agreement (Bonn Agreement 1983) partners, covering shipping activities in the North Sea.

Norway and Russia have agreements regarding cooperation in cases of at-sea incidents in the Barents Sea. The initial agreement on oil pollution was signed in 1994 and the agreement on search and rescue operations in 1995. Since 2003, a joint working group with representatives of the Ministry of Transport of the Russian Federation and the Ministry of Fisheries and Coastal Affairs in Norway meet twice a year to discuss how to improve safety at sea in the Barents Sea.

In 1993, the Copenhagen Agreement was extended to cover the Faroe Islands, Greenland and Iceland, in addition to the original participants Denmark, Sweden, Norway and Finland. In 2007, Norway and Iceland also agreed to start exchanging vessel traffic data for vessels leaving/entering these countries' EEZ.

2 NORWEGIAN EMERGENCY RESPONSE ORGANISATION

The Regional High Command Northern Norway initially had the responsibility for coastal contingency planning and response in Northern Norway. The command had direct access to the resources to be used,

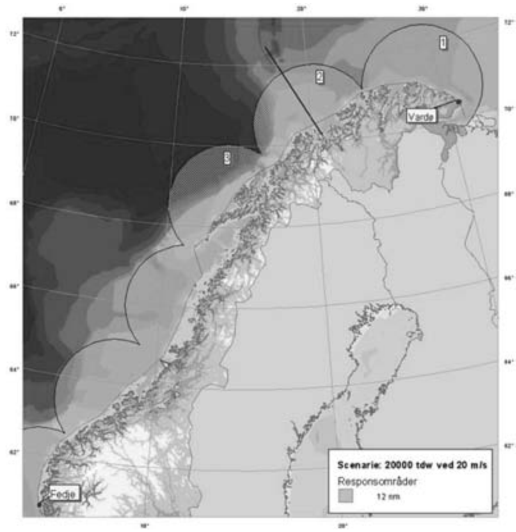

Figure 1. Operational regions for emergency response vessels.

especially Norwegian Coast Guard vessels. In 2005 the Norwegian Coastal Administration's Department of Emergency Response was set up and took over the responsibility from the Regional High Command. The Norwegian Coastal Administration is responsible for the chartered emergency response vessel in Northern Norway.

The contingency planning for acute pollution has three layers; private, community and national. The Norwegian Coastal Administration is responsible for governmental contingency planning and is the executive body for handling large acute oil spills and preventing such accidents. NCA holds responsibility for the governmental towing support service in Northern Norway. Based on a study led by Det norske Veritas (DNV 2006), it was decided to use the following data when specifying the necessary towing capacity for governmental emergency response vessels working off the coast of Northern Norway:

– Hold/manoeuvre vessels up to 100,000 DWT without own power under the following environmental conditions:
  – Wind speed 20 m/s
  – Current speed 1 m/s
  – Significant wave height 5 m

At present two emergency response vessels are on duty during the summer and three in the winter season. These vessels are located as shown in Figure 1.

All vessels are multipurpose vessels and their performance as emergency towing vessels is limited. In a note prepared by the Norwegian Coastal Administration (NCA 2007) the following improvements to the present contingency situation have been proposed:

– Towing vessel capacity should be raised, especially in the summer season

– Oil-spill combating equipment needs to be improved for cold climate operation/low temperatures, icing conditions)
– Training of personnel to handle situations in darkness and at low temperatures

All policy statements made by government agencies and oil companies involved in oil exploration and production off the coast of Finnmark say that "The contingency for shipping and marine operations in the Barents Sea should be the best in the world". There is thus a need for government organisations to develop a common definition of specific objectives and action plans to implement this contingency organisation, purchase necessary equipment (including mission-adapted vessels) and train personnel who will be involved in combating maritime emergency situations.

3 DEVELOPMENT OF SIMULATOR BASED TRAINING COURSE

In the course of the past few years, a number of situations have arisen in which vessels in distress in harsh weather have needed the assistance of emergency towing vessels. To establish an emergency towing connection is a challenging operation, in the course of which the emergency response vessel has to manoeuvre close to the disabled vessel. A highly skilled and experienced master is needed for such an operation. How to train masters for such vessels is a challenge, as emergency towing in harsh weather is a rare event for personnel on other vessels than dedicated emergency towing vessels. Different solutions have been selected nationally and by the major salvage companies for qualification of personnel on emergency response and towing vessels. Generally speaking, it is important to build crews with a strong degree of respect for each other's field of expertise. Companies such as Smit Salvage and Abeilles have their own in-house training program for personnel on board their emergency towing and salvage vessels.

In 2003, the Norwegian Coastal Administration started a project that had two main objectives. The first was to prepare a set of functional requirements for vessels to be used in the authorities' emergency preparedness system. The second was to specify a list of competences needed by senior personnel on emergency response vessels. With this list in hand, NCA reviewed existing training offers in Norway and concluded that these were unable to deliver what they required. They then decided to fund the development of a specific training course to improve the competence level of personnel involved in tasks specified in the National Emergency Towing Contingency Plan. In 2005, SMS was invited to take part in the development of a simulator-based training course as one element of a competence enhancement plan for personnel on emergency response vessels. The Norwegian Coastal Administration appointed an expert group to help SMS to develop a simulator-based training course. It had representatives from:

– The Norwegian Coastal Administration
– The Regional High Command Northern Norway
– The Norwegian Coast Guard
– Tanker operators

The expert group was asked to specify course objectives, evaluate the need for necessary extensions of simulator software and hardware and specify the instructor qualifications needed for this highly specific simulator-based training course. At an early stage it was decided that the target group of trainees should be

– Management and deck operators serving onboard vessels scheduled to form part of the National Emergency Towing Service.
– Shore-based personnel with tasks in the National Emergency Response plan relating to handling disabled vessels.
– The types of training objectives for this course have been divided into the following categories:
– Basic knowledge and understanding of the physics of towing operations
– Towline characteristics
– Handling of the tug when preparing the towline connection
– Procedure training
– Team work and Bridge Team Management

On the recommendation of the expert group, the following items were included in the course programme:

– National and International Regulations
– Towing Vessels and Towing Equipment
– Towing Manual and Standard Procedures
– Preparing for the Towing Operation
– The Towing Operation
– Forces Acting on Disabled Vessel
– Towing Connection and Towing Vessel
– Arrival Port of Refuge
– Simulator Exercises

Relevant chapters from SOLAS and MARPOL as well as national regulations from the Norwegian Maritime Directorate, the Norwegian Coastal Administration and the Regional High Command Northern Norway will be discussed on the course. Parts of the DNV rules for Marine Operations will also be highlighted in some exercises.

For the towing operation the training objectives are related to

– Arrival at disabled vessel
– Pick-up of emergency towing equipment
– High-risk elements during manoeuvring close to the disabled vessel
– Connection of towing equipment
– Operation of towing winch/cable
– Tension in towing cable
– High-risk elements during towing

Figure 2. KV Harstad towing a simulated disabled vessel.

Some of the aspects to be reviewed when the towing connection has been established will be:

- Towing Speed
- Towing Wire Length
- Arrival at Coastline/Port of Refuge
- Towing in Shallow Water
- Towing in Narrow Water
- Towing without Assistant Tug(s)

To be able to start training as early as possible it was decided to start courses using existing simulator models for anchor-handling and platform supply vessels. For these vessels it was necessary to perform some additional force and visual modelling of the towing arrangement, towing gear and towing winch. Figure 2 shows an early visual model of the aft deck of the Coast Guard vessel KV Harstad and the towing line for a calm-water towing operation in confined waters.

The simulator exercises have been developed to enable the trainees to learn more about:

- External forces (wind, current, swell and waves)
- Manoeuvring close to a disabled vessel
- Maintaining disabled vessel in position
- Turning and stopping the drift of a disabled vessel
- Arrival at coastline/Port of refuge
- Towing with assistant tug(s)

Locations for training scenarios were selected so as to represent traffic patterns and for sites where the consequences of an oil spill from a grounding or grounded tanker would be serious. The simulator instructor has the option of changing weather conditions during an exercise. The expert group has prepared a list of failures that can be introduced during simulation runs.

Initially, two test courses with eight participants on each were held, one in May and the other in September 2006. The objective of the test courses was to collect feedback from trainees on course design, course material, exercises and simulator fidelity. Participants were nominated by the Norwegian Coastal Administration. Course participants represented:

- The Norwegian Coastal Administration
- The Norwegian Coast Guard
- The Regional High Command Northern Norway
- Tug operators

Table 2. Evaluation scores of test course participants.

Activity	Topic	Good	Very good	Excellent
Theory	Content	11	5	
	Presentation method	11	5	
	Instructor	6	10	
Exercises	Training goal	6	9	1
	Briefing	10	6	
	Personal challenge	9	6	1
	Debriefing	9	7	

The topics of the three-day test courses can be divided into three main items:

- Introduction to rules and regulations
- Study of previous cases
- Training in the simulator.

In addition to the oral debriefing at the end of these courses, SMS used a one-page written questionnaire. For most of the questions a five-level score form were used. Table 2 shows some of the responses of the participants. Only the top three score levels are shown in the table as there were no items where the two lowest levels were used by the trainees. As can be seen the course was well received by the trainees, who made a number of suggestions on ways to improve the outcome of the course. The written learning material was updated on the basis of feedback from the participants. The briefing and debriefing activities were modified to increase trainee participation.

The results of the evaluation was used to update course content and written learning material as well as to improve simulator software and adapt the visual system to include important cues used by experienced tug masters. The participants recommended that the course should be extended by at least one day.

4 EXPERIENCE FROM ORDINARY COURSES

After the test courses, four ordinary courses were held in 2006. Based on feedback from the test courses the final course length was increased to four days. Participants on the ordinary courses have included representatives of on-board and on-shore management involved in emergency response operations in northern Norway. Table 3 shows the results of the written questionnaire for these courses. For all topics the feedback is more positive than for the test courses shown in Table 2. It can be seen that instructor performance has been improved, training goals made more relevant to real-life operations and the briefing and debriefing sessions made more interesting.

In 2007, 6 courses were run with a total number of 42 participants. The total score showed that course got a mean score of 4.0 on a 1-5 score list (where 5 is top score – or excellent).

Table 3. Evaluation scores from course participants.

Activity	Topic	Good	Very good	Excellent
Theory	Content	13	16	
	Presentation method	10	18	1
	Instructor	1	26	2
Exercises	Training goal	7	21	1
	Briefing	10	19	
	Personal challenge	9	19	1
	Debriefing	11	16	2

In 2008, 5 courses took place with a total of 45 participants. The mean score on the feedback form was slightly higher then for 2007.

4.1 *Improving ship models*

The participants asked for updated mathematical simulator models representing the three vessels that are part of the emergency response system for the winter season in northern Norway. This is due to the important differences in the manoeuvring and seakeeping performance of these vessels. Due to limited personnel resources at SMS the development of ship-specific models will be limited to only one of the emergency response vessels. KV Harstad was selected as a case vessel for the development of a new mathematical model. Part of this work has been done at MARINTEK using the 3 degrees of freedom (DOF) model employed in MARINTEK's SIMAN software (MARINTEK 2005), which is based on:

– Numerical calculation of added mass using VERES
– Empirical expressions for linear damping terms
– Crossflow drag formulation for non-linear damping terms
– Empirical formulae or manufacturers' data for rudder forces
– Empirical formulae or manufacturers' data for propellers and thrusters
– Empirical corrections for hull-rudder-propeller interactions
– Empirical models of wind forces.

To validate the model, MARINTEK has access to model tests for the UT-512 design, which is the basic design for KV Harstad, as well as calm-water manoeuvring tests. As the shipyard delivery tests are very sparse on vessel manoeuvrability, it was necessary to run additional sea tests with the actual vessel. Calm-water standard manoeuvring tests according to IMO recommendations (IMO 2002) were done late October 2006. These measurements were used to tune MARINTEK's calm-water model.

However, emergency response operations will usually take place in a harsh weather conditions. It is thus necessary to develop a complete 6 DOF model for emergency response vessels operating in rough seas. This work is currently under way at MARINTEK. To validate the 6 DOF model a new set of manoeuvring tests was done in relatively harsh seas late November 2008.

4.2 *Other requests for simulator model improvements*

The course participants also asked for more realistic representation of the wave field on the lee side of a disabled vessel. This improvement will eventually be made by manipulating the visual database for the sea surface. There will be no calculations of the actual wave field for a multibody situation. It will not be possible to implement this modification within the time-frame of the ongoing "Arctic Emergency Operations" project. It has also been requested that the visual presentation of the towing line during a towing operation in harsh weather should be made more realistic. Experienced masters will be asked to take part in a face validation of possible solutions to make the visual representation of the towline more realistic. These modifications may be based on simplified mathematical models of the towing line.

5 FIELD EXERCISES

In addition to the simulator based training course deck officers on the chartered emergency response vessels in Northern Norway are performing regular field training exercises to practice the steps of an emergency towing operation. When planning such exercises the Norwegian authorities have paid special attention to drifting tankers due to the increased number of oil tankers operating in or passing close to Norwegian waters. For disabled tankers the challenges presented by an emergency response operation can be divided into three main areas:

– Establishing a towline between the disabled tanker and the support vessel
– Controlling the drifting vessel after towline connection
– Reducing/stopping or removing an oil spill around a disabled tanker.

In general NCA runs about 6-8 field exercises involving commercial vessels annually. The objectives of these training exercises are threefold:

– To train the emergency response vessel crews
– To train the land-based part of the emergency response organization on co-operation, surveillance, alerting and response
– To train the complete emergency response organization to prepare to strand the vessel or assist it to a port of refuge.

In additions to training with merchant vessels, the emergency response vessels run a large number of exercises in which other Coast Guard vessels are simulating the vessel in distress.

5.1 *Special challenges for emergency operations in Northern regions*

For exercises during the winter, sea spray icing may introduce additional challenges. The aft working deck may be slippery and removing ice from equipment may be a dangerous task in a rough sea. Figure 3 shows deck equipment on one of the emergency response vessels prior to starting a field exercise. Low temperatures combined with wind chill restrict the working time for persons on deck. Lack of daylight in the wintertime is an additional constraint to be considered when planning and performing an emergency towing operation. To reduce the workload for deck personnel it is common to head the stern into the waves so that the sea water wash out the ice on deck prior starting the transfer of the towing gear from the Coast Guard vessel to the disabled vessel.

5.2 *Lessons learned from field training exercises*

Field exercises have illustrated some of the problems one can encounter when trying to establish the towing connection. Examples of operational problems include the drifting pattern of released emergency towing gear, large drifting speed of the disabled vessel, mismatch of connecting shackles and lack of information regarding towline force. The following statements are taken from debriefing discussions after field exercises:

- Rigging a towing connection to a drifting vessel is a complex task even under good weather conditions. Manoeuvring an emergency response vessel close to a large drifting vessel is a complex task even for a vessel with high-quality manoeuvring performance.
- Towing large vessels in heavy weather conditions requires good manoeuvring performance of the towing vessel and a towing arrangement designed for ocean towing.
- Drifting of the messenger line for a released ETS depends on weather and current conditions. Handling of the emergency response vessel to get in a position to pick up the messenger line can be difficult, especially at night and with reduced visibility
- Shackles delivered from the emergency response vessel may be too large to fit bulwark openings on vessels built before IMO ETS requirements were approved. There are a number of different arrangements for strong points, ETS and ways of arranging an emergency towing connection. NCA has therefore developed a questionnaire that is forwarded to all vessels entering the control zone for Vardø VTS. Ships are requested to forward drawings and procedures for establishing emergency towing connections. NCA has developed a database for ETS and strongpoint arrangements on vessels in regular oil and gas traffic in Norwegian Exclusive Economic Zone areas.
- Qualification of personnel on emergency rescue vessels must include training in emergency towing operations.

Figure 3. Removing ice on the aft deck prior to a field training exercise.

6 USING R&D RESULTS FROM "ARCTIC EMERGENY OPERATION" TO IMPROVE TRAINING OF DECK OFFICERS ON NORWEGIAN EMERGENCY RESPONSE VESSELS

Since 2006, the Ship Manoeuvring Simulator Centre has managed an international research and development project on Arctic emergency operations. More information on this project can be found on the project website http://www.arcemop.no. One of the work packages is investigating best practice for emergency towing operations. An important activity has been to arrange workshops for sharing operational experience on emergency towing operations. Experienced tug masters have been invited to present real-life cases in which they have been involved. Representatives of emergency response organizations in a number of European countries and Japan have taken part in the seven workshops arranged by the project.

The field tests with KV Harstad described in section 4 have been a part of this project. The Norwegian Coast Guard has made the vessel available for field testing throughout the project period. In May 2008 a special towing test took place where KV Harstad established an emergency towing connection and towed a 70.000 dwt tanker at low speed in confined waters. The outcome of this test has been used in validation studies of a new version of the Japanese software tool "Optimum Towing Support System" developed by National Maritime Research Institute (T. Koruda & S.Hara, 2007).

7 CONCLUSIONS

Based on information from project partners and external contributors, the following conclusions have been drawn:

- There is no internationally accepted functional specification of an emergency towing vessel
- Most countries specify parameters such as necessary bollard pull, speed in calm water and draught.
- It is proposed that more effort should be put into operational characteristics such as speed,

manoeuvrability and motion characteristics in rough seas, towing gear, etc.
- From an economic point of view most nations prefer multipurpose vessels as emergency response vessels
- Salvage operations will be carried out by professional salvage companies using their best available rescue tugs

To handle large disabled vessels in harsh weather situations, dedicated ETVs will have a higher probability of a successful operation than multipurpose vessels. The professional skill of the ETV crew is a critical success factor in establishing a towing connection in harsh weather and to prevent the towing wire from breaking in heavy-weather towing.

On the basis of the conclusions listed above, it is recommended that a potential follow-up project should focus on these topics:

- Specifying the necessary equipment on an ETV in order to simplify different ways of hooking up to a drifting vessel
- Specifying a range of tactics to be used when handling a disabled vessel in a heavy-weather situation
- Improving the ability to position the ETV close to the casualty
- Transnational sharing of emergency towing experience and training of crew members on emergency response vessels.

ACKNOWLEDGMENTS

The authors would like to thank shipping companies for making vessels available for emergency towing training exercises. The Research Council of Norway is acknowledged for their financial support to the project "Arctic Emergency Operations" under their MAROFF program. Their support has made it possible to run additional training exercises as well as a number of international workshops on emergency towing operations to investigate functional specifications of emergency towing vessels, operation of such vessels and training of personnel on emergency rescue vessels. Finally we will thank participants on SMS training courses for their valuable input to continuously improve the training course for personnel in the northern Norway emergency response organization.

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Chapter 3. Global navigation satellite system

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

3.1
Modernization of maritime DGPS in Poland

M. Dziewicki
Maritime Office, Gdynia, Poland

ABSTRACT: Some new techniques and functionality adopted for modernization of national DGPS systems by maritime administrations in Europe are presented. Any solution adopted must meet international requirements: IMO standards and IALA e-NAV Committee recommendations. The results of DGPS Re-capitalization Meeting in Gdynia 2008 are presented. Modernization and re-engineering of maritime DGPS must take into account backward compatibility with existing onboard receivers as well as future trends towards e-Navigation. Operational and legal status of the Polish DGPS network is also mentioned in this context.

1 INTRODUCTION

Most of mariners use Global Navigation Satellite Systems (GNSS) as a primary means of navigation. Currently available GNSS does not fulfil the requirements of IMO with respect to accuracy and integrity. The use of IALA maritime DGNSS does fulfil these requirements. International maritime standards exist for both: onboard receiver and land based DGNSS service. The system has been widely adopted as the international maritime standard for providing differential corrections to GNSS. The IALA DGPS beacon systems were installed in many countries over the period 1993–2000 and now became obsolete. The Radio-navigation (presently e-Navigation) Committee concluded that there is a requirement to recapitalise national systems. It is potentially a good reason to re-organise the system for the benefit of existing users and to enhance DGNSS capabilities taking into account technical innovations. At the same time some countries are considering submission of their DGNSS services to IMO as components of the World Wide Radio Navigation System.

2 IALA OPTIONS

The key system of secure marine navigation and accurate hydrographic survey is reliable radionavigation service. The IALA Radio-navigation Committee has assessed the current and potential use of the DGNSS system and concluded that there is a requirement to continue existing service and to modernise the system and develop enhanced GNSS capabilities as well as alternative technologies to meet the requirements of IMO Resolution A.915(22). There are several alternatives to the IALA beacon system for the transmission of differential corrections and safety related information. There are methods of providing enhanced services, like e-Loran, Eurofix, EGNOS, AIS, Real Time Kinematic (RTK) or pseudolites. Their related basic features and a subjective cost are listed in Tab. 1., [2].

The simplest modernization option may be replacement of existing equipment with new dedicated hardware Reference Stations and Local Integrity Monitors (RSIM). This solution could limit the potential for future development. Additionally modernization

Table 1. Alternative techniques for IALA DGNSS

System	Accuracy	Coverage	Instant warning Integrity/Continuity	Cost Provider/user	Maritime standard
IALA DGNSS	1–3 m	local/regional	Yes/High	Moderate/low	yes
EGNOS	5–10 m	regional/global	Yes/High	Very high/low	no
AIS	1–20 m	local	Can be/Moderate	Low/low	yes
Pseudolites	sub-meter	local	Yes/Moderate	High/moderate	no
Eurofix	2–10 m	regional	Yes/High	low/moderate	no
RTK	sub-meter	local	Can be/Low	Moderate/high	no

of DGNSS should be considered in the context of position-fixing requirements for e-Navigation.

The future need could be providing additional messages relating to Galileo, GPS L2C/L5 and GLONASS M should be taken into account.

Other possibilities include:

– Software Reference Stations and Integrity Monitors (RSIM)
– Virtual Reference Station (VRS),
– SBAS (EGNOS, WAAS) Integration

Above options are explored further in IALA Recommendation R-135, [3].

Finally IALA members are encouraged to:

– Recapitalize existing DGNSS systems prior to their obsolescence, noting the advice given in R-135,
– Consider the options for replacement systems, with reference to the documents listed below,
– Share information regarding studies carried out and specifications of replacement solutions, and report progress to IALA,
– Investigate potential future developments compatible with the development of shore based e-Navigation architecture,
– Investigate techniques for adding value to transmissions, such as transmission of safety related information and/or backup positioning capabilities, [1].

3 DGPS RE-CAPITALIZATION MEETING IN GDYNIA

The meeting *"DGPS re-capitalization"*, was hosted in May 2008 by Maritime Office Gdynia, in Gdynia. The development of a strategy for future implementing of local and regional augmentation systems was noted. The response of representatives at the meeting indicate that most administrations providing DGNSS services are undertaking re-capitalisation or are planning such activities based also on co-operation with National Geodetic Networks.

– Sweden is currently studying options for software RSIM solutions and transmissions of VRS data via MF beacon system taking into account also geodetic network SWEPOS.
– Germany is planning to implement DGNSS recapitalization plan by creating RAAS and VRS based on national network operated from national centre of control. The new concept of "moving centre of system accuracy" was presented. Also a new type of MF transmitting antenna (NTA) was presented. Germany also announced a feasibility study to investigate the addition of Ranging signals (R-Mode) on MF beacon and AIS carriers, [1].
– Scotland referred to the common UK and Ireland studies of DGPS replacement options which concluded that the lowest risk option for the GLAs would be hardware replacement, although the flexibility provided by the software option would better meet emerging requirements and should not be ruled out. The GLAs have tendered for new RSIM equipment, which may be fulfilled by either hardware or software solution, [1].
– Russia is testing broadcast of DGlonass and DGPS corrections via AIS system in Golf of Finland.

4 MODERNIZATION OF POLISH RADIONAVIGATION

Maritime Office Gdynia (MOG) has established and operates shore based/costal network to support DGPS, RTK, and AIS systems. These were built and organized to fulfill international IMO standards and recommendations endorsed by IALA.

Polish DGPS system has already been fully modernized during the period 2007–8, to meet all the requirements set out in IMO Resolution A.915(22) for Future GNSS. The hardware RSIM solution has been adopted for the re-capitalisation, on grounds of low cost and market availability. The conception is based on a network of reference stations and remote integrity monitors continuously operated via IT links from a common control center.

The DGPS-PL system is composed of two reference beacon stations which are remotely operated and controlled via wide area network from the Control Station located in Gdynia. Both existing reference stations RS Dziwnów and RS Rozewie are equipped with two reference L1, L2 receivers, two MSK modulators and dual LF beacon transmitters. Local integrity monitors (RSIM model) are being under permanent control via WAN from Central Station in Gdynia. A dedicated server at the control center continuously gathers operational information from all sites. Thus living database of Regional Area Corrections can be created in the future. There are also plans to integrate marine system with a national geodetic network EUPOS to transmit VRS data via MF beacons.

4.1 *Integrity of DGPS-PL*

To ensure signal availability at required level of (99,5%) for single site beacon station, a redundancy of major hardware is fundamental, therefore each RS station is doubled and operation will continue in case of a hardware failure. The set of RTCM messages and broadcast frequencies from Polish DGPS beacon stations is shown in Table 2.

Quality of DGPS broadcast is being checked and evaluated by local integrity monitors (RSIM). Additionally the range and signal availability will be monitored by remote LF DGPS monitors. Daily reports and data on availability of the system are gathered in data base of Central Control server in Gdynia.

4.2 *Integrity Settings (IM)*

It was recognised that certain integrity monitor threshold settings are vital to the proper performance of the

Table 2. Polish DGPS marine stations

Station name	Identification Reference Station(s)	Transmitting beacon	Geographical Position Lat/Lon	Station in operation	Integrity Monitoring	Transmitted message types	Freq (kHz)	Bit Rate (bps)
Table of DGNSS Stations			**Country: POLAND**		Date of last amendment: Sept 2008			
Dziwnów	741 742	481	54°01′N 14° 44′E	yes	yes	9,3,7,16	283.5	100
Rozewie	743 744	482	54° 49′N 18°20′E	yes	yes	9,3,7,16	301.0	100

Table 3. Characteristics of RTK RS-Hel

Name RS- Hel	**Receiver type**	**Corrections output**	**Radio-transceiver**	**Options**
System	Net R-5	RTCM 18, 19,20, 21	Satelline 3AS Epic, simplex	VRS
Application	GPS, Glonass	Binary code CMR, CMR+	UHF 2-10W range 10–40 km	RTK, DGPS
Frequency	L1,L2,L5	1 Hz	434.25 MHz	+/−1 MHz
Link Mode	Network (LAN)	serial, NMEA	RS com	VPN

RS station. IALA Recommendation R-121 contains the list of parameters and recommended settings, [4]. The local integrity monitor continuously checks the quality of the own DGPS transmissions by receiving and applying own corrections. Thus the IM software monitors position accuracy, signal availability (SNR), tracked satellites, GPS geometry (DOP), RTCM data correctness and quality, as well as radiated signal level (SS). When alarm condition is detected, an alarm message is immediately set for local response and switching to optional equipment (secondary configuration) can happen. Any IM message warning will automatically be broadcast to all users/ships in the area within 10 s.

5 RTK SERVICE

Permanent reference RTK station was established on Peninsula Hel to cover Gdańsk, Gdynia ports and approaching routes. Real Time Kinematics solution using carrier-phase corrections has the enhanced accuracy, but there are constraints imposed by the bandwidth and spatial de-correlation. For single RTK station, the range is up to 10–40 km (Table 3). This is sufficient for hydrographical and engineering applications in the Gulf of Gdańsk, can also be used during docking phase in the ports. Station operation is fully controlled via network from RL Gdynia, however radio signal strength and position accuracy is being monitored by IM receiver situated permanently in the port of Gdynia. It is highly recommended that in the near future RS-Hel will be incorporated into Polish geodetic RTK network ASG-PL. In result the whole system would benefit of better marine coverage and VRS technique would become available along the Polish coastal zone.

6 CONCLUSIONS

– Re-capitalization process of national DGNSS systems is well advanced, however IALA members are at different stages of developing, concerning available options versus budgetary constrains.
– All of new solutions must meet the need of existing users taking into account existing and future IMO, IALA regulations.
– Re-capitalization of national DGNSS gives good opportunity to modernize technique and functionality towards new e-Navigation requirements.

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3.2 Application of 3-D velocity measurement of vessel by VI-GPS for STS lightering

Y. Yoo & E. Pedersen
Norwegian University of Science and Technology, Trondheim, Norway

K. Tatsumi
Hiroshima National College of Maritime Technology, Hiroshima, Japan

N. Kouguchi
Kobe University, Kobe, Japan

Y. Arai
Marine Technical College, Ashiya, Japan

ABSTRACT: A lightering operation is a type of Ship-To-Ship (STS) operation where two ships are together in open waters and transfer the cargo e.g. crude oil, LNG. High skills and experience are required by the human operators as no relevant equipment for determining the relative speeds and distances with sufficient accuracies has been implemented. The officer in charge of an STS lightering takes the decision on adequate maneuvering orders based on predominantly visual observations during the final approach. Landing on all fenders simultaneously is an objective in order to minimize ship-fender contact forces, but this is rather difficult to achieve in practice even in calm sea due to the effect of hydrodynamic interaction when the ships are closing in. Furthermore, currents that are present in the lightering zone add to the operational complexity. A field measurement experiment has been carried out with a Velocity Information GPS (VI-GPS) system installed onboard a ferry approaching port for berthing which is similar to an STS lightering. The paper proposes to apply VI-GPS as input sensor to a decision-support and guidance system aiming to provide accurate velocity information to the officer in charge of an STS operation. It is argued that DOP of VI-GPS is related to the velocity error.

1 INTRODUCTION

Applications of ship-to-ship operations for cargo transfer are expected to be increasing. Currently, about 25 percentages of all oil imported to the US comes through lightering operations. An ongoing research program on Ship-To-Ship (STS) operations with focus on STS lightering has a major objective to develop a guidance and decision-support system for the key operative personnel. The initial approach phase can be regarded as a collision avoidance maneuver which aim is to obtain the required safety distance, while the final approach is maneuvering towards the other ship and operation alongside until the ships have been moored together after which cargo transfer can commence. STS operations are individually different because of variations in the environmental conditions and the maneuvering characteristics of ships.

The final approach phase is particularly critical in order to avoid steel to steel contact. The officer in charge of an STS lightering, the Mooring Master, has currently no equipment at his disposal for determining the relative speeds and distances with sufficient accuracies and the decision of adequate maneuvering orders is thus mainly based on visual observations (Pedersen et al. 2008).

The velocity of a movable body can be easily determined by using the GPS receiver generated Doppler measurement or the carrier-phase derived Doppler measurement as long as the satellite velocity is precisely known. The kinematic GPS (K-GPS) is well known to provide accurate positions. Although K-GPS assures high precision measurement in a cm order of magnitude, it is required that the reference station on land is within 20 km of the moveable body (Hou et al. 2005).

A method for precise velocity measurement using Velocity Information GPS (VI-GPS) is described for STS lightering ship. The Doppler measurement generated by GPS receiver is a measure of instantaneous velocity that is measured over a very short time interval, whereas the carrier-phase derived Doppler measurement is a measure of mean velocity between observation epochs. The velocity integration with respect to time is the displacement during a period between the two epochs (Hou et al. 2005).

In this paper, an experiment has been conducted onboard a ship entering port for berthing where the velocity information by VI-GPS was used for measuring precise 3-D velocity (longitudinal, transverse and vertical). The results has been compared with those of K-GPS and evaluated with respect to DOP (Dilution Of Precision) of VI-GPS (Hoffmann-Wellenhof et al. 2004).

2 CONCEPT OF SHIP-TO-SHIP OPERATION

A Ship-To-Ship (STS) transfer operation is an operation where cargo (e.g. crude oil or petroleum products) is transferred between seagoing ships moored alongside each other. Such operations may take place when one ship is at anchor or when both are underway. In general, the operational phases includes the approach maneuver, berthing, mooring, hose connecting, safe procedures for cargo transfer, hose disconnection, unmooring and departure maneuver (ICS & OCIMF, 2005).

In the case of maneuvering alongside with two ships at forward speed, the ship acting as the Ship-To-Be-Lightered maintains steering speed (approximately 5 knots) and keeps a steady course heading. It is normal that the maneuvering ship, also referred to as the Service Ship, approaches and berths with the port side to the starboard side of the STBL.

The other case of maneuvering is that the STBL is at anchor, which is quite common in STS operations. For such operations, the STBL anchors in a pre-determined position using the anchor on the opposite side to where the maneuvering ship will approach. A berthing operation should only be carried out after the ship at anchor is lying on a steady heading with reference to prevailing environmental conditions.

Figure 1 shows the final stage with both ships maneuvering alongside with forward speed in calm seas.

Figure 1. The two ships have come alongside and commenced mooring operation while still underway at slow forward speed. The ships will be brought dead in the water and the STBL is to anchor if the operation takes place in a lightering zone with shallow waters.

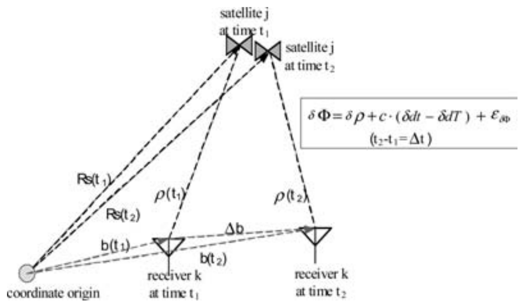

Figure 2. Time differential carrier phase measurement by Velocity Information GPS.

3 VELOCITY INFORMATION BY GPS

The observation equation for the GPS carrier phase measurements is the following (Hou, 2005):

$$\Phi = \rho + c\cdot(dt - dT) + \lambda N - d_{ion} + d_{trop} + \varepsilon_{\Phi} \qquad (1)$$

where Φ is the carrier-phase observation; ρ is the geometric distance between a satellite and a receiver; c is the light speed in vacuum; dt, dT are the receiver and satellite clock error; d_{ion}, d_{trop} are the ionospheric and the troposheric delay; ε_{Φ} is the receiver noise and multipath error.

3.1 *Velocity Information GPS (VI-GPS)*

The velocity information GPS uses the epoch single difference technique and the first order central difference approximation of the carrier-phase rate.

Time differential observations are obtained by subtracting the observations at the previous epoch, k-1 from those at the present epoch, k. It is assumed that variations of propagation errors in the ionosphere and troposphere are small and negligible when the interval of observations is short. The time differential observation is expressed in the following equation and temporal differences remove the phase ambiguities:

$$\delta\Phi = \delta\rho + c\cdot(\delta dt - \delta dT) + \varepsilon_{\delta\Phi} \qquad (2)$$

Here, the symbol δ means the time differential operator, and $\delta\Phi$ is the phase observation in temporal difference between two epochs. In discrete expression of Equation 2, the phase difference between two sequential epochs is measured as following equation:

$$\Phi_k^j \approx \frac{\Phi_{k+\Delta t}^j - \Phi_{k-\Delta t}^j}{2\cdot\Delta t} \qquad (3)$$

where superscript j represents the satellite; k and Δt are the observation epoch and time interval of the observation, respectively. Figure 2 shows the time differential carrier phase measurement by VI-GPS.

The observation equation can be written as the following:

$$\mathbf{L} = f(\mathbf{X}) + \mathbf{V} \qquad (4)$$

$$\mathbf{L} = [\delta\Phi_1, \cdots, \delta\Phi_N]^T$$

$$\mathbf{X} = [\delta\rho_1 + c\cdot(\delta dt_1 - \delta dT), \cdots, \delta\rho_N + c\cdot(\delta dt_N - \delta dT)]^T$$

where **X** is the vector of observations; $f(*)$ is the vector of known function mapping **X** to **L**; **X** is the vector of unknown parameters; **V** is the vector of residuals; subscript $_N$ is satellite number; and ^{T} is vector transposition.

The equation must be linearized with respect to unknowns before performing the least-squares adjustment. Linearization of Equation 4 is made by replacing the nonlinear functions with their Taylor series approximations at the point an initial value of the solution vector, $\mathbf{X}^0$ and taking only the first order terms.

$$\mathbf{L} - f(\mathbf{X}^0) = \frac{\partial f}{\partial \mathbf{X}} d\mathbf{X} + \mathbf{V} \tag{5}$$

$$\mathbf{W} = \mathbf{A}\mathbf{X} + \mathbf{V} \tag{6}$$

where **W** is the misclosure vector, $\mathbf{L} - f(\mathbf{X}^0)$; **A** is the design matrix of partial derivatives evaluated using $\mathbf{X}^0$; and the vector of residuals.

Assuming that the matrix **A** at the present epoch k is identical to the one at the previous epoch k-l, the least-squares solution of Equation 6 is the displacement between the two epochs. The misclosure vector $\delta\mathbf{W}$ that is obtained from Equation 2 is distinguished from the observation equation for positioning obtained Equation 1.

$$\delta\mathbf{W} = \mathbf{A} \cdot \delta\mathbf{X} + \mathbf{V} \tag{7}$$

When the weight of measurement is not equal, the equation must be weighted with an observation weight matrix **P**. If the technique with double difference observation is used, the mathematical correlation has to be taken into account, using the matrix **P**. The normal matrix **N**, the vector **U** and the least-squares solution are derived from the application of the least-squares principle ($\hat{\mathbf{V}}^T\mathbf{P}\hat{\mathbf{V}} \to \min.$) to Equation 7 as follows:

$$\mathbf{N} = \mathbf{A}^T\mathbf{P}\mathbf{A} \tag{8}$$

$$\mathbf{U} = \mathbf{A}^T\mathbf{P}\delta\mathbf{W} \tag{9}$$

$$\delta\hat{X} = N^{-1}U \tag{10}$$

Observation at a one second interval gives a solution for unit displacement, i.e. velocity. Using the position from absolute positioning with a single GPS receiver as a prior position, the least-squares solution provides the correction to the a priori position.

3.2 *Kinematic GPS (K-GPS)*

The kinematic GPS uses the double differences technique and the carrier phase observation equation is the following (Tatsumi, 2008):

$$\Delta\nabla\Phi = \Delta\nabla\rho + \Delta\nabla d\rho + \Delta\nabla\lambda N - \Delta\nabla d_{ion} + \Delta\nabla d_{trop} + \varepsilon_{\Delta\nabla\Phi} \tag{11}$$

where $\Delta\nabla$ is the double difference operator. The double differences technique needs two receivers. The reference station is set as a fixed point on land, while the rover station is set on the movable body. When the distance between the two stations are within 20 km, the orbital and atmospheric errors, $\Delta\nabla d\rho$, $\Delta\nabla d_{ion}$ and $\Delta\nabla d_{trop}$ are illuminated. Equation 11 then becomes as follows:

$$\Delta\nabla\Phi = \Delta\nabla\rho + \Delta\nabla\lambda \mathrm{N} + \varepsilon_{\Delta\nabla\Phi} \tag{12}$$

It is well known that over four double differences carrier phase observations from four satellites can decide precise kinematic GPS 3-D position of the rover station, $\mathbf{P}_{rover}$. The velocity of the movable body is calculated from the time differential operation of this precise rover 3-D position as follows:

$$\mathbf{V} \approx \Delta\mathbf{P} = \frac{\mathbf{P}_{rover}^{k+\Delta t} - \mathbf{P}_{rover}^{k-\Delta t}}{2 \cdot \Delta t} \tag{13}$$

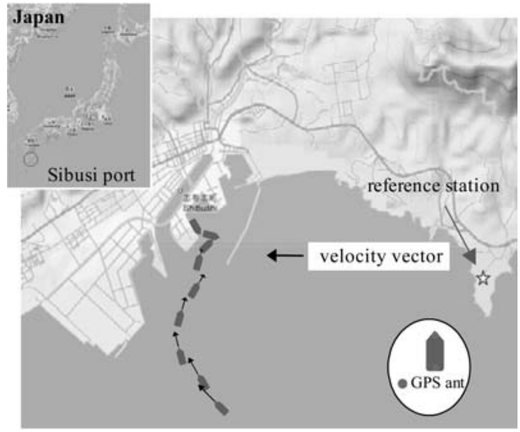

Figure 3. Experimental area overview of Sibusi port.

Table 1. General specification of the ferry, data details and experimental conditions.

Gross tonnage	12,418 [tons]
Service speed	23.0 [knots]
Length overall	186.0 [m]
Width	25.5 [m]
Sampling frequency	5 [Hz]
No. of data samples	8000
No. of GPS satellites	7
(satellites no.)	(no. 5, 9, 12, 14, 18, 22, 30)

4 SIMULATED STS OPERATION

A simulated STS operation was carried out with a ferry on 17th of September, 2007 when it was entering the Sibusi port of Kagoshima prefecture that is located in southwest of Japan. Figure 3 shows the experimental area overview. The ferry was equipped with two GPS receivers that were located on stern and bow, respectively.

The first part (800 sec) of the approach was similar to a STS maneuver with the STBL at anchor. It should be noted that during the time range around 800–1300 seconds the ferry turned backward to the berth, which is a maneuvering that is not taking place in any

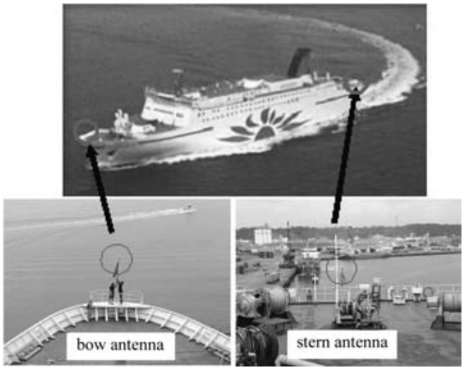

Figure 4. The ferry and positions of GPS receivers.

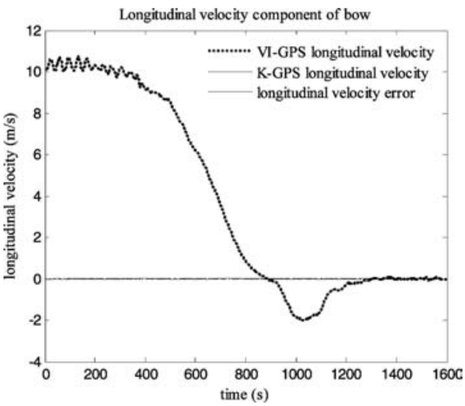

Figure 5. Longitudinal velocity component of bow.

STS operation. The reference station was about 3 km apart from the berth while the maximum distance from the ferry (rover station) was 7 km. (It is well known that K-GPS accuracy has cm order if the reference station is within 20 km from the rover station.)

Table 1 shows the general specification of the ferry, data details and experimental conditions. The experimental period was about 27 minutes from standby for entering port until stop engine order with 5 Hz data sampling frequency. The number of data samples was 8000 recorded by PDA (Personal Digital Assistance), and each GPS receiver processed the same GPS signals transmitted by 7 GPS satellites. Figure 4 shows the ferry and the two GPS receivers set on the bow and stern side.

K-GPS data was calculated from the reference station data to rover station while VI-GPS data was calculated from rover station alone. In this paper, the velocity by K-GPS is defined as a standard velocity, and then the velocity error subtracts K-GPS velocity results from VI-GPS results.

4.1 *Experimental results*

Figures 5–7 show the results of longitudinal, transverse and vertical velocity components of bow, respectively.

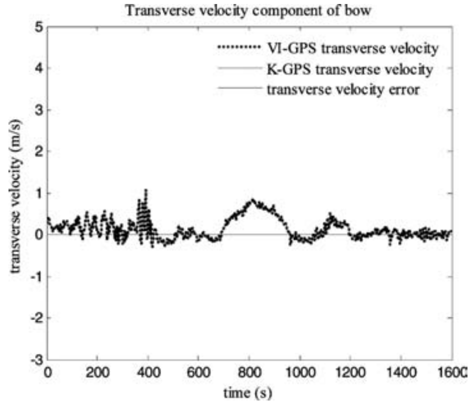

Figure 6. Transverse velocity component of bow.

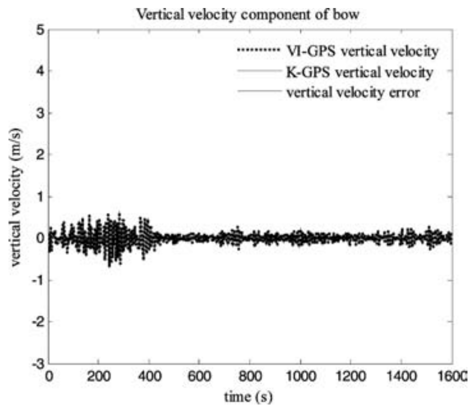

Figure 7. Vertical velocity component of bow.

Figure 5 shows the longitudinal velocity components by VI-GPS with black dot line, K-GPS with blue line and longitudinal velocity error with red line subtracted the longitudinal velocity component by K-GPS from VI-GPS result. The velocity is decreasing from around 11 m/s to zero during the recorded logging time. The velocity is oscillating the first 400 seconds which is due to low frequency waves (swell) outside the breakwater. As is shown, the two results by VI-GPS and K-GPS show a good correspondence. Figure 6 shows the transverse velocity components of bow. VI-GPS and K-GPS results also show a good correspondence, and similar to the longitudinal velocity results. Figure 7 shows the vertical velocity component and the velocity error also has a small difference.

Figures 8–10 show the results of longitudinal, transverse and vertical velocity components of stern, respectively. Figure 8 shows the longitudinal velocity components by VI-GPS with black dot line, K-GPS with blue line and velocity error with red line subtracted K-GPS results from VI-GPS results. The results are oscillating during the first 400 seconds due to the swell. Two results by VI-GPS and K-GPS show a good correspondence, similar to the bow results, and its velocity error also shows smaller difference compared

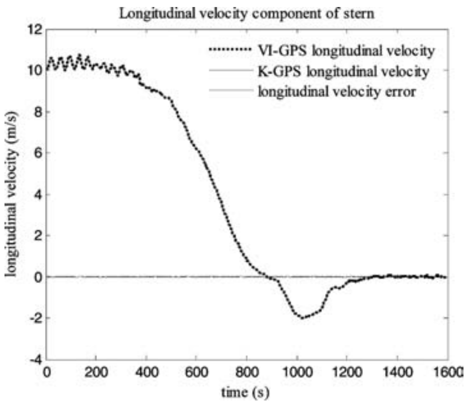

Figure 8. Longitudinal velocity component of stern.

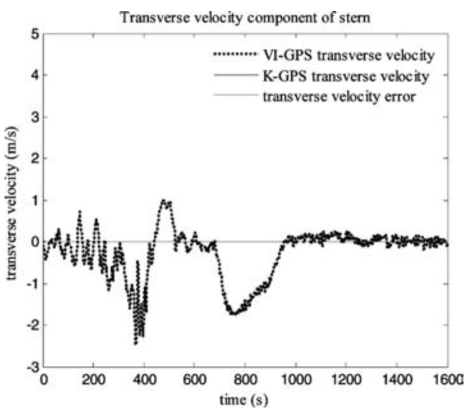

Figure 9. Transverse velocity component of stern.

to the longitudinal velocity error. Figure 9 shows the transverse velocity component of stern. As same with the results of bow, it shows a good correspondence with VI-GPS and K-GPS results. Figure 10 shows the result of vertical velocity component of stern. The results show a good correspondence between VI-GPS and K-GPS results, and the vertical velocity error subtracted K-GPS results from VI-GPS results shows small difference.

Table 2 is the results of longitudinal, transverse and vertical velocity errors subtracted K-GPS results from VI-GPS results. From the results, the velocity errors of bow side show slightly higher standard deviation values than stern side velocity errors. Among the velocity errors at bow, the vertical velocity error shows the largest standard deviation value with 0.72 cm/s. The vertical velocity error at stern also shows large value with 0.70 cm/s standard deviation.

4.2 *Considerations*

From the results showing bow velocity errors the standard deviations of longitudinal, transverse and vertical velocity errors have been analyzed. In order to identify the relation between velocity errors and DOP

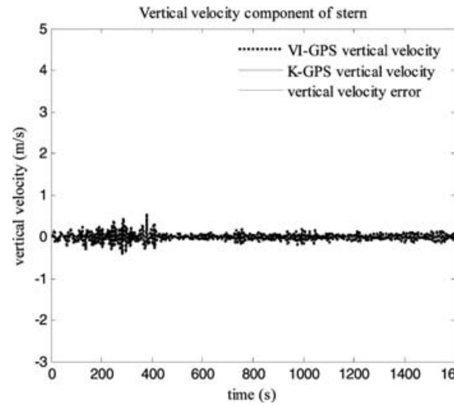

Figure 10. Vertical velocity component of stern.

Table 2. Longitudinal, transverse and vertical velocity errors of bow and stern sides.

Bow	Longitudinal V-error	Transverse V-error	Vertical V-error
Mean (cm/s)	−0.03	−0.13	−0.06
Std (cm/s)	0.24	0.22	0.72
Stern			
Mean (cm/s)	−0.04	−0.13	−0.07
Std (cm/s)	0.22	0.21	0.70

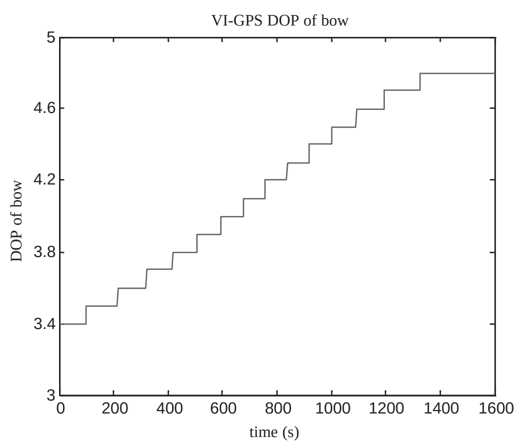

Figure 11. VI-GPS DOP of stern side.

(Dilution Of Precision), DOP changes of VI-GPS was also examined as well as the relation with bow velocity errors.

Figure 11 shows how the VI-GPS DOP changes at the bow side. DOP is increasing according to time progression from 3.4 to 4.8. Figure 12 shows the relation between bow velocity errors and DOP changes of VI-GPS divided into every 100 seconds. In the figure, blue Δ, red · and black + symbols show the standard deviation of longitudinal, transverse and vertical velocity errors with respect to DOP changes,

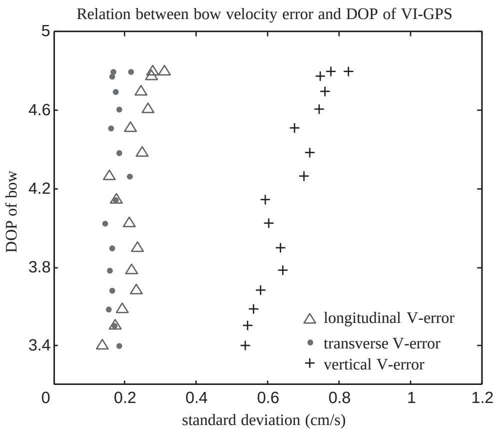

Figure 12. Relation between bow velocity error and DOP of VI-GPS.

respectively. According to the increase of DOP, the standard deviation of longitudinal and vertical velocity errors are increasing, but the transverse velocity error does not show a particular increase according to DOP changes compared to other velocity errors. As shown in Figure 12, VI-GPS can be used with a good accuracy within 1 cm/s standard deviation if DOP could be obtained under 4.8.

In the final approaches of STS lightering operation, the longitudinal and transverse velocity information is very important for the mooring master. Therefore, more precise relation between DOP and longitudinal, transverse velocity errors has been shown in Table 3 with vertical velocity error as well. Table 3 shows the standard deviations of longitudinal, transverse and vertical velocity errors with respect to DOP changes of VI-GPS at bow. The velocity error shows a small standard deviation within 1 cm/s when DOP is under 4.8. The vertical velocity error has increased gradually according to DOP increase from 0.54 to 0.83 cm/s. Even though, it shows high values of 0.83 cm/s with maximum velocity error compared to other velocity errors, it is considered that VI-GPS has an enough accuracy under 1 cm/s. Furthermore, because the longitudinal and transverse velocities are mainly used as important information in the final approaches of STS lightering operation, the vertical velocity error can be negligible.

5 CONCLUSIONS

STS operations represent a challenge to the officer in charge because currently there is no equipment implemented that can provide the relative speeds and distances with sufficient accuracies. Decision of adequate maneuvering orders is then based on visual observations. VI-GPS has been applied to measure precise 3-D velocity (longitudinal, transverse and vertical) for STS operations. The advantage is that precise accuracy is not limited to distances within 20 km as the case of K-GPS.

Table 3. Standard deviation of longitudinal, transverse and vertical velocity errors with respect to DOP changes of bow.

Data no. (sec)	DOP	Longitudinal std (cm/s)	Transverse std (cm/s)	Vertical std (cm/s)
1–200	3.4–3.5	0.14	0.18	0.54
101–200	3.5	0.17	0.17	0.54
201–300	3.5–3.6	0.19	0.15	0.56
301–400	3.6–3.7	0.23	0.16	0.58
401–500	3.7–3.8	0.22	0.16	0.64
501–600	3.8–4.0	0.24	0.16	0.63
601–700	4.0–4.1	0.21	0.14	0.60
701–800	4.1–4.2	0.17	0.17	0.59
801–900	4.2–4.3	0.16	0.21	0.70
901–1000	4.3–4.4	0.25	0.18	0.72
1001–1100	4.4–4.6	0.22	0.16	0.68
1101–1200	4.6–4.7	0.27	0.18	0.74
1201–1300	4.7	0.24	0.17	0.76
1301–1400	4.7–4.8	0.27	0.16	0.75
1401–1500	4.8	0.28	0.22	0.78
1501–1600	4.8	0.31	0.17	0.83

An experiment representing a simulated STS operation was done in Sibusi port of western Japan during entering the port. The results of VI-GPS velocity showed a good correspondence with K-GPS velocity results, i.e. within 1 cm/s.

From the result of relation between bow velocity errors and DOP of VI-GPS, 3-D velocity by VI-GPS has precise accuracy within 1 cm/s level compared to K-GPS if DOP of VI-GPS can be obtained under 4.8. The longitudinal and transverse velocity of bow side showed standard deviation of 0.24 and 0.22 cm/s, respectively. It is considered that VI-GPS has sufficient accuracy to serve as sensor input for providing relative velocities in a decision-making and guidance system tailored for STS operations.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

3.3 Positioning using GPS and GLONASS systems

L. Kujawa, J.B. Rogowski & K. Kopańska
Warsaw University of Technology, Warsaw, Poland

ABSTRACT: This paper presents an experiment involving the processing of observations using the GPS and GPS/GLONASS systems performed at the BOGO, BOGI, and JOZ2 IGS stations. Due to the small number of GLONASS satellites, the authors failed to receive any significant improvement in positioning accuracy using GPS and GLONASS observations jointly.

1 INTRODUCTION

The slogan "GPS/GLONASS satellite measurements" has become popular recently. Judging by news provided by the press, including Inside GNSS, one may get the impression that the GLONASS system is making its comeback and the number of active satellites in the system is steadily growing. This was the reason for an increase in our interest in the joint utilisation of both navigation systems in practice, especially after the correction of the Russian reference system with respect to the ITRF system with only a centimetre shift parameters (September 2007). What remains is the problem of differences in the time scale, but nothing seems to demonstrate that this is particularly significant. So, what is it we did in order to confirm the impact of observations of GLONASS satellites on the accuracy of GNSS positioning? We conducted an experiment for which we selected monthly data (September 2007) from the BOGO, BOGI, and JOZ2 stations (BOGO and BOGI are very close to each other while JOZ2 is at a distance of approximately 42 km). The observations were processed using Trimble Total Control software as the network of selected points is not vast. The network of vectors connecting the specified points was designated using two alternatives. The first only used GPS observations while the second applied both systems – GPS and GLONASS. The quantity and configuration of GLONASS satellites makes impossible the independent analysis of observations exclusively from the GLONASS system. In spite of the placement of successive GLONASS system satellites in orbit, the number of active SVS has not changed as of this day. The Russian's efforts are concentrated on replacing the old type satellites with new ones.

2 THE EXPERIMENT

What was done was a comparison of vector determinations for the GPS and GPS/GLONASS data. Two types of vectors were considered: long (forty-two kilometre) and short (one hundred metre) ones. The vector components, long and short, of the determinations from daily cycles were characterised by a mean error of 2 mm, and nothing seems to suggest any change in the values of the vector components or their accuracy characteristics in terms of both solutions conducted using data exclusively from GPS and utilising observations made using the two systems. Figure no. 1 presents changes in the "long" vector components calculated for daily observation cycles. The equalised coordinate values for the three points earmarked for the experiment for solutions using only GPS data and those using both systems gave identical results with an accuracy of result presentation.

The lack of any discernable difference in results for the daily solutions induced us to conduct an analysis of DOP coefficients, making possible an assessment

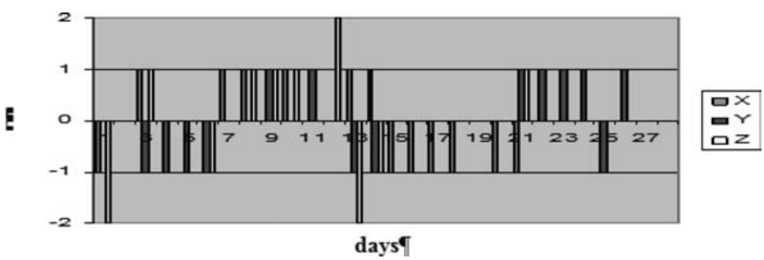

Figure 1. Changes in the BOGI-JOZ2 vector components in a 3D system.

of the "strength" of the solutions in relation to satellite numbers and configurations.

3 GDOP (GEOMETRICAL COEFFICIENT)

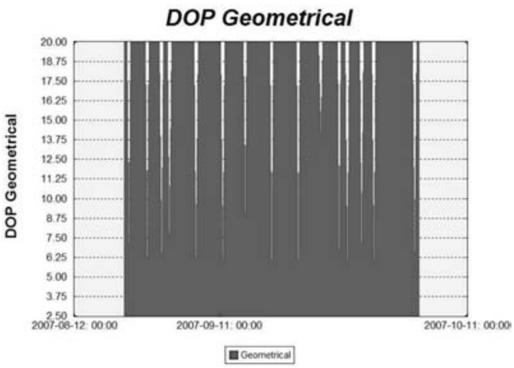

Figure 2. GDOP for the GLONASS system.

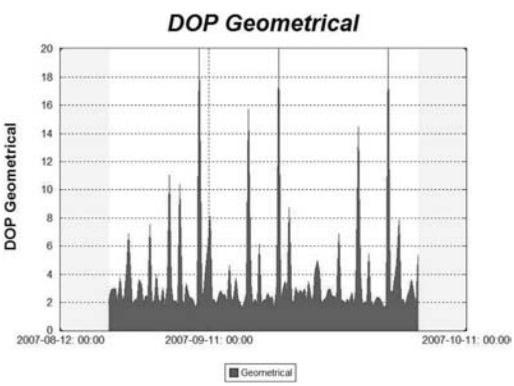

Figure 3. GDOP for the GPS system.

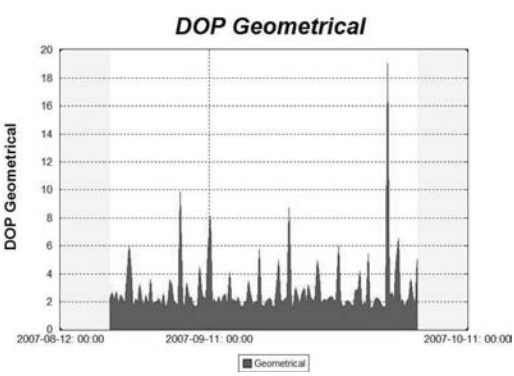

Figure 4. The common GDOP for GPS/ GLONASS systems.

4 HDOP (2D SOLUTIONS) AND VDOP (HEIGHT)

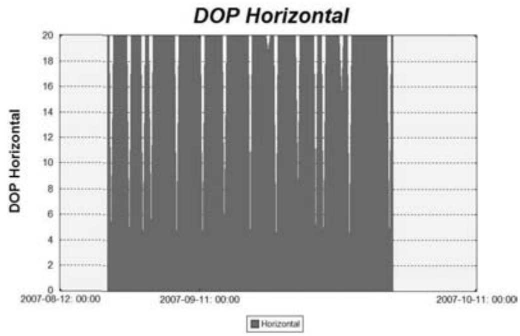

Figure 5. HDOP coefficient for the GLONASS system.

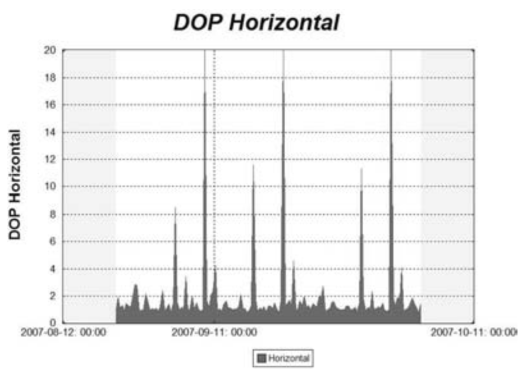

Figure 6. HDOP coefficient for the GPS system.

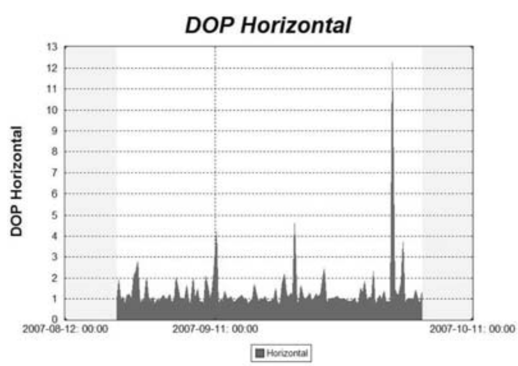

Figure 7. The common HDOP coefficient for the GLONASS and GPS system.

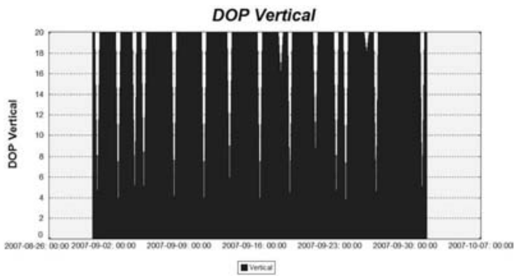

Figure 8. VDOP coefficient for the GLONASS system.

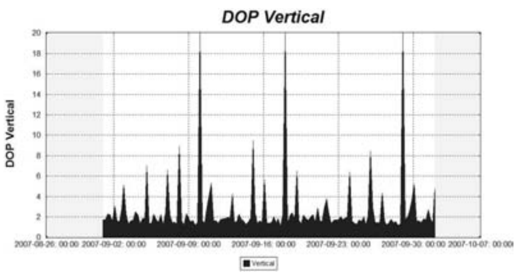

Figure 9. VDOP coefficient for the GLONASS system.

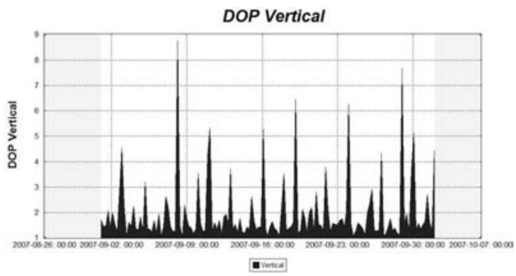

Figure 10. The common VDOP coefficient for both systems.

5 PDOP (PRECISION COEFFICIENT FOR DETERMINATION OF 3D POSITION)

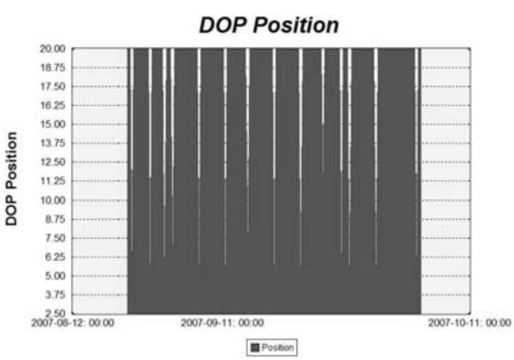

Figure 11. PDOP coefficient for the GLONASS system.

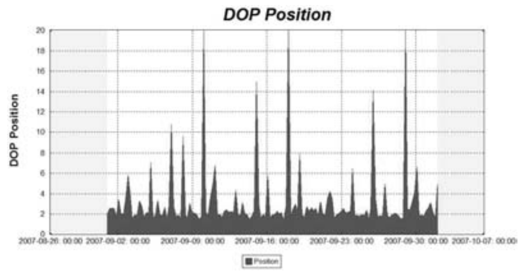

Figure 12. PDOP coefficient for the GPS system.

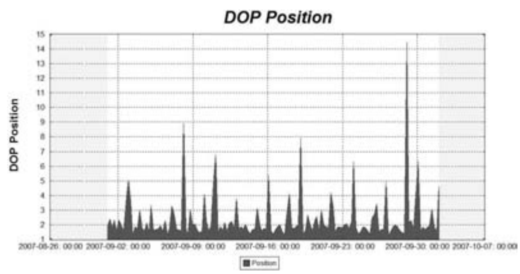

Figure 13. The common PDOP coefficient for both systems.

6 TDOP (TIME DILUTION OF PRECISION)

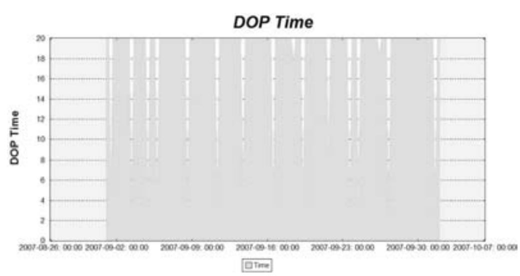

Figure 14. TDOP coefficient for the GLONASS system.

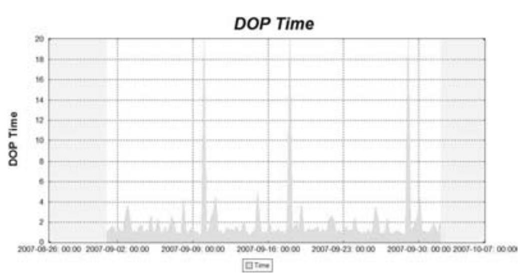

Figure 15. TDOP coefficient for the GPS system.

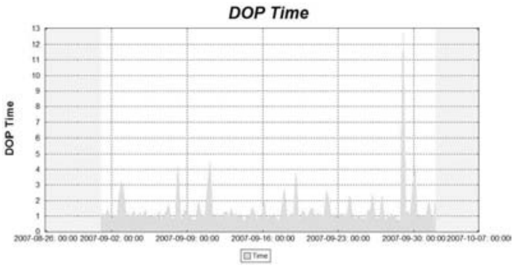

Figure 16. The common TDOP coefficient for both systems.

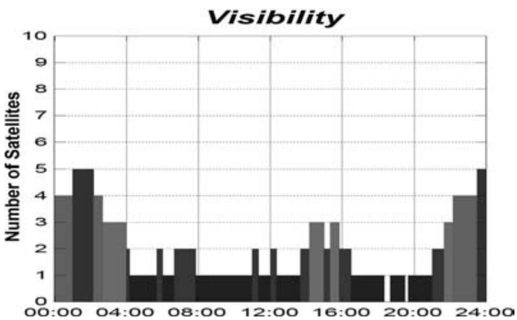

Figure 17. GLONASS satellite visibility in Warsaw.

7 DOP ANALYSIS SUMMARY

All DOP graphs are strongly correlated – firstly with the number of observed satellites, and secondly with their placement in the horizontal hemisphere. They confirm that 3D or even 2D positioning using only GLONASS satellites is, in practice, senseless. This is confirmed by the sample Figure no. 16 which presents the number of GLONASS satellites visible over a twenty-four hour period in the vicinity of Warsaw.

In practice, the use of the GLONASS system in addition to the GPS system gives very poor results. The DOP coefficients fall insignificantly, which has no major impact on accuracy achieved. The GPS system provides DOP coefficients of a value below three for the decided bulk of the time.

The only situation in which the Russian satellites might have a major impact on accuracy would be a situation in which the GPS satellite was low over the horizon, while the GLONASS satellites would be high. The measurement would be improved in such a case. However, analysis of almanacs for GPS shows that such situations are very rare and their duration is very short.

8 CONCLUSIONS

The objective of this experiment was to compare position determination in the GPS and GLONASS systems as well as applying combined solutions. It was demonstrated that:

– As of today, it is difficult to speak of the determination of position exclusively on the basis of GLONASS satellites.
– The past year has seen the replacement of old type satellites with new ones – GLONASS-M – rather than expansion of the space sector as stated by *Inside GNSS* (the number of active satellites has not changed over the year).
– If one is to believe the promises of the Prime Minister of Russia (dated from before the crisis), one can have hopes that by the end of 2009 the system will be expanded to an operational state. However, nothing seems to support this premise.
– The compensatory effect of the two systems (albeit it is difficult to unequivocally state if this is not temporary) may be considered a promising premise for the future, when the number of GLONASS satellites approaches an operational level.

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3.4
Galileo integrity concept and its applications to the maritime sector

C. Hernández, C. Catalán & M.A. Martínez
GMV S.A., Madrid, Spain

ABSTRACT: Galileo is the European Global Navigation Satellite System, under civilian control. Galileo will provide their users with highly accurate global positioning services and their associated integrity information. The main objective of this article is to explain the basis of the Galileo integrity concept, which is fundamental for safety-critical applications such as maritime navigation. A review of the expected performance that will be achieved has been also included.

1 INTRODUCTION

Galileo is the European Global Navigation Satellite System, under civilian control. Galileo will provide to their users highly accurate global positioning services and their associated integrity information. The element within the Galileo Ground Mission Segment (GMS) in charge of the computation of Galileo integrity information is the IPF (Integrity Processing Facility), being developed by GMV (Grupo Mecanica del Vuelo).

The integrity algorithms of the GMS are responsible of providing a real-time monitoring of the satellite status with timely alarm messages in case of failures. The accuracy of the integrity monitoring system is characterized by the SISMA (Signal In Space Monitoring Accuracy), which is broadcast to the users through the integrity message together with the satellite integrity flags (OK, Not Monitored, Do Not Use).

Galileo is currently in its detailed design and development phase. The design and development phase for the IPF started in May 2005. The Critical Design Review (CDR) of the system has been successfully at the beginning of 2008, while the Factory Qualification Review (FQR) is expected for 2009. The SW prototypes of the integrity algorithms have already been implemented and the assessment of the critical performance figures has already been performed with outstanding results.

The main objective of this paper is therefore to explain the basis of the Galileo integrity concept, which is fundamental for safety-critical applications such as maritime navigation. It will include the mathematical formulation that shall be present at receiver level together with the details that are required to understand it from the maritime user point of view. A review of the potential level of performance based on the preliminary results available from the development phase will be also provided.

Additionally, information is provided related to the potential evolutions of the Galileo integrity concept, which is currently being defined in the frame of the GNSS evolution program led by ESA and in the 7th Framework Program of the European Commission led by the GSA, in which GMV takes an active role. In this environment, requirements from the maritime user community are being considered.

2 THE GALILEO INTEGRITY CONCEPT

2.1 *Overview*

Integrity can be defined as a measure of the trust that can be placed in the correctness of the information supplied by the system. Integrity includes the ability of the navigation system to provide users with timely and valid warnings (alerts) when the system must not be used for the intended operation (ICAO, 2006). In the current Galileo baseline the integrity aspects concerning the SIS errors will be achieved by means of two parameters: Signal-In-Space Accuracy (SISA) and the Integrity Flag (IF). Together with a new satellite ephemeris and clock models broadcast to the users, it is also sent the SISA, which is a prediction of the associated errors with a certain confidence level for the whole coverage area and valid for the applicability time of the models. The computation of this parameter is performed in another element of the GMS named OSPF (Orbitography and Synchronization Processing Facility) based on off-line data processing. Additionally, in order to meet the stringent integrity requirements such as the maximum Time To Alert (TTA), it is broadcast in real time the Integrity flags, which inform the users if SISA is properly bounding or not the SIS errors in that moment.

The Signal-In-Space Accuracy (SISA) plays an important role in the Galileo integrity concept, as it should cope with the navigation message errors

Table 1. Galileo Overbounding definition.

The distribution of a random variable A is over-bounded by a distribution of a random variable B, if for all $L \geq 0$:
$P(\|A\| \geq L) \leq P(\|B\| \geq L)$ for all $L \geq 0$

in fault-free conditions. The description of the algorithms in charge of the SISA computation is out of the scope of this paper, which is devoted to the real-time integrity monitoring system of Galileo allocated to the IPF.

2.2 *High-level description*

In order to validate the navigation message being broadcast by the satellites, an independent estimation of the Signal-In-Space Error (SISE) is performed in real-time. This estimation, which is also modeled as a random process with an associated uncertainty, allows the verification of the overbounding of the true SISE distribution by the broadcast SISA. The assumption made in this case is that the difference between the true SISE projected at Worst User Location (WUL) and the estimated one can be overbounded by a Gaussian distribution with the standard deviation equal to SISMA. In this context, the SISMA can be considered as a quality measure of the integrity check within the IPF. Additional information on the Galileo integrity concept can be found in (Oehler, 2005). From the operational point of view, the IPF design does not consider any real-time human intervention, so key factors are the algorithms' robustness and reliability, directly derived from the stringent integrity and continuity requirements.

Before entering more deeply in the explanation of the Galileo user integrity concept and its potential applications for the maritime community the Galileo overbounding concept should be clarified. As stated in (Hernández, 2008), it can be defined in the following way:

This definition of the Galileo overbounding concept is quite similar to the CDF (Cumulative Density Function) overbounding definition stated by (DeCleene, 2000), although there are some differences as explained in (Hernández, 2008).

The objective of the IPF is to validate the navigation message of the satellites. The validation is based on IPF estimation of the SISE and its comparison with the broadcast SISA and the internally computed SISMA. According to the assumptions mentioned earlier, the IPF will assume that the estimated SISE is overbounded by a Gaussian unbiased distribution:

- True SISE overbounded by $N\,(0, SISA)$;
- SISE estimation error (True SISE minus Estimated SISE) overbounded by $N\,(0, SISMA)$;
- Estimated SISE overbounded by $N(0, \sqrt{SISA^2 + SISMA^2})$;

Under these assumptions, the user considers that the threshold applied at IPF level in order to decide if a navigation message is valid or not is given by the variance of the distribution characterizing the estimated SISE, together with the required false alarm probability:

$$T = k_{pfa,u} \cdot \sqrt{SISA^2 + SISMA^2} \quad (1)$$

$$If \quad (Estimated\ SISE > T) \quad \Rightarrow \quad IF = Do\ not\ use \quad (2)$$

being $k_{pfa,u}$ the point of the normal distribution that leaves in the tails (two-tail problem) a probability equal to the specified false alarm rate. Thus, if the estimated SISE projected to the worst user location is higher than the allowed threshold, the satellite is flagged as "DO NOT USE" in order to indicate the user that its navigation message is not valid and the satellite should not be used for positioning.

The current specification of the IPF element envisages a maximum false alarm probability in the order of 10^{-7} in 15 seconds, which gives a $k_{pfa,u}$ factor approximately of 5.212. Considering that the required values for SISA and SISMA are 0.85 and 0.7 meters, respectively, in case no more barriers were implemented, the minimum detectable errors by the IPF would be in the order of 6 meters.

2.3 *User integrity risk computation*

Galileo users will compute the Integrity Risk (IR), which is the probability of having Hazard Misleading Information (HMI). This will come out as a result of a combination of the horizontal and vertical errors, considering both the fault-free situation (FF) and the one where there is one failing satellite (1F). The case of multiple satellite failures is excluded from the user integrity risk computation since they are covered by other mechanisms established in the Galileo system Fault Tree Analysis (FTA). It is important to note that satellites with an IF set to "DO NOT USE" will be excluded from the user position and integrity computation.

The basic underlying assumptions allowing the user to determine the integrity risk of his position solution at any global location are:

- In a "Fault-Free-Mode" the true SISE for a satellite is overbounded by a zero-mean Gaussian distribution with a standard deviation equal to SISA;
- In general, the IPF will detect the faulty satellites and they will be flagged as "don't use";
- One satellite of those flagged as "OK" is considered to be faulty but not detected ("Failure Mode"). For this satellite the true SISE is overbounded by a Gaussian distribution whose mean is the "IPF rejection threshold" (T) and the standard deviation is equal to SISMA, *N(T,SISMA)*;
- The probability that more than one satellite at each instance in time is faulty but not detected is negligible for the user equation.

Table 2. Galileo Integrity Risk Computation.

IR = Vertical_IR + Horizontal_IR =
Vertical_IR_FF + Vertical_IR_1F +
Horizontal_IR_FF + Horizontal_IR_1F

Therefore the computation of the integrity risk is as follows:

$$P_{HMI}(Error_v, Error_h) = P_{IntRisk,V} + P_{IntRisk,H} =$$
$$1 - erf\left(\frac{Error_v}{\sqrt{2}\cdot\sigma_{u,V,FF}}\right) + \exp\left(-\frac{Error_h^2}{2\cdot\xi_{FF}^2}\right) +$$
$$\frac{1}{2}\cdot\sum_{j=1}^{N} P_{fail,sat=j}\cdot\left(\left(1-erf\left(\frac{Error_v+\mu_{u,V}}{\sqrt{2}\cdot\sigma_{u,V,FM}}\right)\right) + \left(1-erf\left(\frac{Error_v-\mu_{u,V}}{\sqrt{2}\cdot\sigma_{u,V,FM}}\right)\right)\right) + \quad (3)$$
$$\sum_{j=1}^{N} P_{fail,sat=j}\cdot\left(1-\chi^2_{2,\delta u,H}cdf\left(\frac{Error_h^2}{\xi_{FM}^2}\right)\right)$$

Table 3. Galileo OS/SoL system performance requirements (without considering the receiver contribution).

Parameter	Performance
Positioning accuracy (95%)	4 m horizontal; 8 m vertical
Integrity Risk	≤ 2.0e-7 in any 150 s
Continuity Risk	≤ 8.0e-6 in any 15 s
Availability of Service	100% nominal 99.5% degraded at WUL
Time To Alert	≤5.2 seconds
Horizontal Alert Limit (HAL)	12 m
Vertical Alert Limit (VAL)	20 m
Coverage	Worldwide

Table 4. Galileo OS/SoL system performance allocation.

Parameter	Performance
Navigation Message ranging accuracy (67%)	65 cm
SISA (67%)	85 cm
SISMA	70 cm Nominal GSS network 130 cm Degraded GSS network
GSS network	40 sensor stations

3 EXPECTED PERFORMANCE

The Galileo system will provide different services: the Open Service (OS) providing positioning and timing, the Commercial Service (CS) that will disseminate additional ranging information on a fee-based scheme, the Public Regulated Service (PRS) providing positioning, timing and integrity for restricted-access signals and the Safety of Life (SoL), which will provide integrity messages for the navigation data included in the OS signals.

As any other navigation system providing integrity, the SoL requirements can be expressed in terms of accuracy, availability, continuity and integrity. The following table summarises the main Galileo system requirements.

In order to be compliant with the currently specified requirements, the design of the Galileo system must take into account several critical aspects, which are usually called performance drivers. First of all, it needs to be clarified that the expected performance are similar to those of EGNOS, but with a global coverage instead of a regional one. Therefore the design of Galileo has been conditioned to a large extent for the compliance to the requested performance. Moreover, performance averaging over time or geographical location is not allowed, which brings additional constraints.

The performance allocation to the different components of the system has been a very complicated process (Oehler 2008). Extensive simulations and computations were requested to derive the current figures. The most relevant ones are presented hereafter.

In order to meet the availability and continuity requirements, it was required to consider not only the nominal configuration of the system but those degraded ones in which elements of the system were missing, giving degraded performance. This is the reason why the SISMA performance is specified with the nominal and degraded GSS networks.

After the detailed performance analysis and algorithm design, most of the performance figures are expected to be accomplished, although some areas need further work. For example, the ionospheric scintillations have been found to be one of the major threats affecting the performance, since they may imply a signal quality degradation and even signal loss, resulting in visibility gaps for certain satellites. This is also present at user level, and it can not be mitigated or compensated at system level, affecting also to DGNSS and SBAS. This threat is nevertheless location-dependent, since it affects the equatorial and high-latitude regions and they are sufficiently frequent so as to be considered as an intrinsic part of the environment, even in years of low solar activity. (Schlarmann, 2008) shows that the current assessment of the expected level of performance is in line with the requirements except for the conditions in which scintillations are present.

Another performance driver is the quality of the raw data provided by the Galileo Sensor Stations (GSS). Both the pseudorange and carrier phase measurements are requested by the algorithms in charge of computing the SISA and SISMA. Advanced filtering and data processing techniques are being used; however the level of multipath at sensor station level will be a critical factor for the achievement of the performance.

4 POTENTIAL EVOLUTION AND APPLICABILITY TO MARINE NAVIGATION

In principle, there is an important aspect in the Galileo Integrity Concept compared with the operational user requirements established by IMO in its resolution for future Global Navigation Satellite System (IMO, 2001). IMO established the requirements for integrity based on the concepts of alert limits and integrity risk. While in principle they are the same concepts as those specified for Galileo, the implementation at system level is different from the one done in SBAS systems such as EGNOS and WAAS (RTCA, 2006). In SBAS, the user computes a Protection Level, defined as the region for which the missed alert probability requirement (or integrity risk) can be met, and compares it with the Alert Limit. In Galileo, the design is in the other way round, the user computes the integrity risk corresponding to the Alert limit and then compared with the maximum affordable limit. IMO's resolution does not preclude one implementation or the other, although it seems to follow a common approach with ICAO (International Civil Aviation Organisation), which introduced the concept of Protection Level in its SARPS (Standard And Recommended Practices for GNSS).

Another important difference is the definition of the Signal-In-Space in terms of the broadcast integrity information. SBAS systems rely on the UDRE (User Differential Range Error) for satellite differential correction residual errors, which is similar to the parameter with the same name introduced in DGNSS (IALA, 2004). However, in the case of Galileo the concept of differential correction no longer applies and the predicted accuracy of the broadcast navigation message is disseminated as the SISA, while the accuracy of the integrity monitoring system is also broadcast as the SISMA. SISA and SISMA (including the integrity alerts) play a similar role to the UDRE.

Although IMO has established operational requirements independently of the implementation of the integrity concept, at the end it will be forced to define a standard for the signal definition for future GNSS in the frame of the maritime policy as it did in the past with DGNSS. The situation is the same as for ICAO and the use of Galileo SoL (Safety of Life) service in the frame of the civil aviation community. Because of these reasons, an effort is currently being done in order to support the harmonisation of the Galileo integrity concept and the existing standards that may envisage some evolutions on this respect in the future.

However, a very important aspect of Galileo as a navigation system providing integrity is its worldwide coverage. With an accuracy in the same order of magnitude as DGNSS and SBAS, the advantage of providing seamless integrity performance over the world may bring a huge benefit in terms of a reduction in the investment in the implementation and maintenance of coastal DGNSS networks. Similarly the future plans for the third generation of GPS satellites include the provision of integrity. On this respect, an assessment done by IMO establishes that Galileo could be considered in the future for Oceanic, Coastal, Port approach and restricted water operations (IMO 2003).

Because of the importance of the provision of integrity in the future, both the European Space Agency (ESA) and GSA (GNSS Supervisory Authority) have launched several projects to analyse the potential evolution of the Galileo Integrity concept. A key factor in this process is the interoperability of Galileo at the level of integrity with other existing system, including SBAS. Some preliminary results on the application of the concept of "transparency" to Galileo can be found in (Catalán, 2008). Additionally, the conception of GNSS as a "system of systems" will probably have a significant role in the evolution of Galileo and its integrity concept. In 10 to 20 years, the most probable situation is that users will have at least four GNSS with open dual frequency signals, GPS, Galileo, GLONASS and COMPASS and more than 20 satellites always in view. With such level of redundancy, the level of performance that could be achieved by RAIM (Receiver Autonomous Integrity Monitoring) algorithms in terms of availability could be fully comparable to those already provided by SBAS or in the future by a standalone use of Galileo. Moreover, it has the clear advantage that includes FDE (Fault Detection and Exclusion) due to local effects (interference, multipath, etc.) that is neither present in DGNSS, SBAS or Galileo, combined with a Time To Alert (TTA) of just 1 second. This RAIM applied to the all the systems together could be even enhanced by the use of the integrity information broadcast by each system. Other options alternative to RAIM are also being investigated, such as the RANCO (Range Consensus) algorithm, see (Schroth 2008), in which several groups of 4 satellites are define in order to evaluate the pseudorange of the satellites that did not enter into the position solution. Based on the information coming from the different solutions some satellites are rejected. As it can be seen, there is a consensus that in the case of multiconstellation GNSS the hypothesis that the probability of a multiple satellite failure is negligible is no longer valid.

Therefore the situation would be that each individual system could work in a standalone mode, providing a certain service level in terms of integrity performance, but their combination would yield a better service level. For this, an effort in the satellite navigation community should be required to standardise the requirements for the different satellite navigation systems in terms of interoperability at the level of integrity.

5 CONCLUSIONS

The Galileo Integrity Concept has been presented, as it has been defined and including the required processing at user level. The major difference with respect to SBAS system specification is the substitution of the Protection Level by the Integrity Risk as the variable to be computed at user level. Because of the introduction of terms corresponding to a potential failure in one satellite, the concept can not be directly reversed into a Protection Level to be compared with an Alarm Limit. This implies a change at implementation level, which represents a deviation from the standard defined by ICAO for civil aviation and, in principle, could be adopted also by IMO. However, the system can be compliant with the high-level system requirements, providing a similar level of performance to those of SBAS and perhaps slightly worse to those of DGNSS, but with the great advantage of a global coverage and therefore no investment at local level.

Additionally, the integrity concept of GNSS will still evolve in the incoming years motivated by the appearance of new satellite navigation systems and the upgrade of the existing ones. GNSS will be conceived as a "System of Systems", each one providing service in a standalone mode and with improved performance when all combined together.

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3.5
Galileo AltBOC E5 signal characteristics for optimal tracking algorithms

F. Vejražka, P. Kovář & P. Kačmařík
Czech Technical University in Prague, Czech Republic

ABSTRACT: The paper deals with an optimal processing of a Galileo E5 signal. A proposed correlator structure was developed on a base of a deep study of an E5 signal cross correlation function. Due to the non linearity of the E5 AltBOC modulation the proposed correlator calculates the cross correlation function between a received signal and a signal replica for all possible hypotheses of the navigation message bits. A correct peak tracking verification is realized by implementation of a single side band correlator, which also serves for course signal acquisition and secondary ranging code synchronization. The signal processing was verified on the Galileo Giove A and Giove B satellites with very positive preliminary results.

1 INTRODUCTION

The Galileo system is a civil satellite navigation system currently developed by the European Union. The system will provide different types of services for various missions, from a basic so called open service (OS) to safety of life service (SoL) and public regulated service (PRS). The Galileo signal structure is therefore very complicated and utilizes wideband signal with an AltBOC modulation for high precision range measurement.

This paper is focused on the signal processing methods of complete AltBOC Galileo E5 signal, which is the most complex Galileo signal with the widest frequency bandwidth. The optimal methods of the GNSS signal processing are well known and are based on the correlation reception. The navigation receiver calculates cross correlation function of the received signal and a locally generated replica signal and synchronized the replica on the received signal.

The optimal correlator structure for Additive White Gauss Noise Channel (AWGN) is the classical Early-Late correlator. The structure of such correlator for GPS L1 C/A signal can be found in Kaplan (1996). The replica generation for GPS L1 C/A signal is very simple, because the unknown navigation data bits are modulated by the linear BPSK modulation.

The proposed signal processing algorithm for the GALILEO E5 signal is based on the same principles like the GPS L1 C/A processing, but the correlator structure is more complex.

2 GALILEO E5 SIGNAL CHARACTERISTIC

The Galileo signals are defined in ESA (2008). The cross correlation function of the signal was derived in Kačmařík (2008) and can be written as follows

$$R_{sr_{E5}}[m]=\left(\frac{1}{2\sqrt{2}}\right)^2\frac{1}{S}\left(\Re[m]+\mathrm{j}\Im[m]\right), \tag{1}$$

where

$$\begin{aligned}\Re[m]=&\sum_{n=-\infty}^{\infty}\left[\begin{matrix}\left(R_{sr1}[n]+R_{sr2}[n]+R_{sr3}[n]+R_{sr4}[n]\right)\cdot\\ \left(\rho_{11}[m-nSN]+\rho_{22}[m-nSN]\right)\end{matrix}\right]+\\ &+\sum_{n=-\infty}^{\infty}\left[\begin{matrix}\left(\bar{R}_{sr1}[n]+\bar{R}_{sr2}[n]+\bar{R}_{sr3}[n]+\bar{R}_{sr4}[n]\right)\cdot\\ \left(\rho_{33}[m-nSN]+\rho_{44}[m-nSN]\right)\end{matrix}\right]\end{aligned} \tag{2}$$

and

$$\begin{aligned}\Im[m]=&2\sum_{n=-\infty}^{\infty}\left\{\begin{matrix}\left(R_{sr1}[n]+R_{sr2}[n]-R_{sr3}[n]-R_{sr4}[n]\right)\cdot\\ \rho_{12}[m-nSN]\end{matrix}\right\}+\\ &+2\sum_{n=-\infty}^{\infty}\left\{\begin{matrix}\left(\bar{R}_{sr1}[n]+\bar{R}_{sr2}[n]-\bar{R}_{sr3}[n]-\bar{R}_{sr4}[n]\right)\cdot\\ \rho_{34}[m-nSN]\end{matrix}\right\}\end{aligned}. \tag{3}$$

The replica signal of the Galileo E5 signal depends on four secondary code bits and two navigation message bits. Since the secondary codes of the data channels are multiplied by the navigation message bits, the cross correlation function generally depends on four bits. It results in sixteen possible shapes of the cross correlation function between received signal and generated replica. All of them are depicted in Figure 1, where 1 or −1 in a chart title indicates bits agreement or disagreement respectively.

The secondary code bits are known in the receiver and can be generated after secondary codes

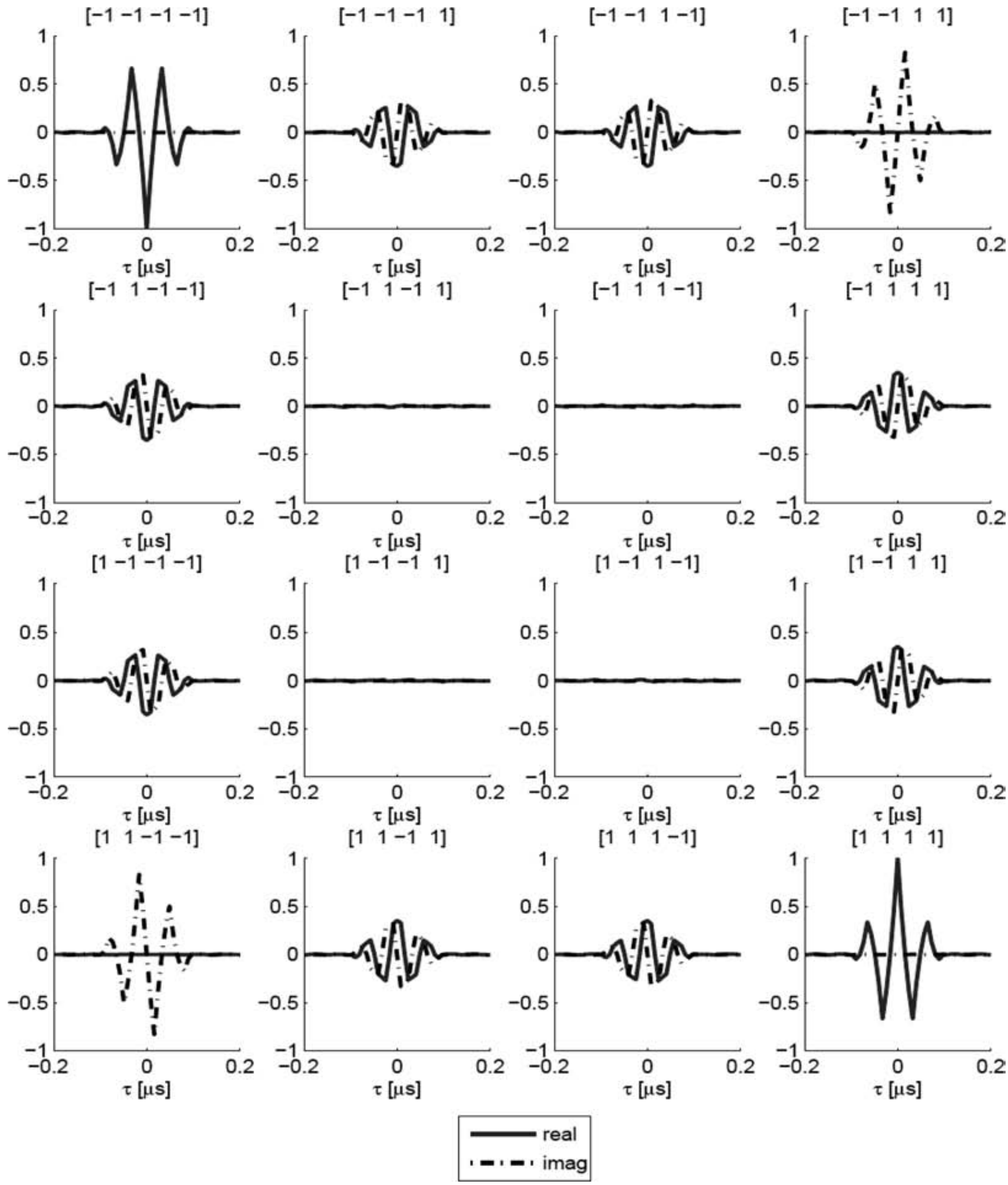

Figure 1. Cross correlation function of received signal and replica for all combination of secondary codes bits.

synchronization, but the navigation message bits remain unknown.

3 E5 CORRELATOR

The structure of the Early – Late correlator for Galileo E5 signal is complicated since the complex AltBOC modulation is used. There is no linear dependency of the modulated signal on the navigation message bits like in the GPS L1 C/A signal. The replica signal therefore must be generated for all possible hypotheses of the navigation unknown parameters. In general case we have to generate 16 replicas. The number of hypotheses can be reduced on four hypotheses after the secondary code synchronization.

This approach gives rise to the correlator structure shown in Figure 2. The first four correlator branches serve for a calculation of the cross correlation function for all combinations of the navigation message

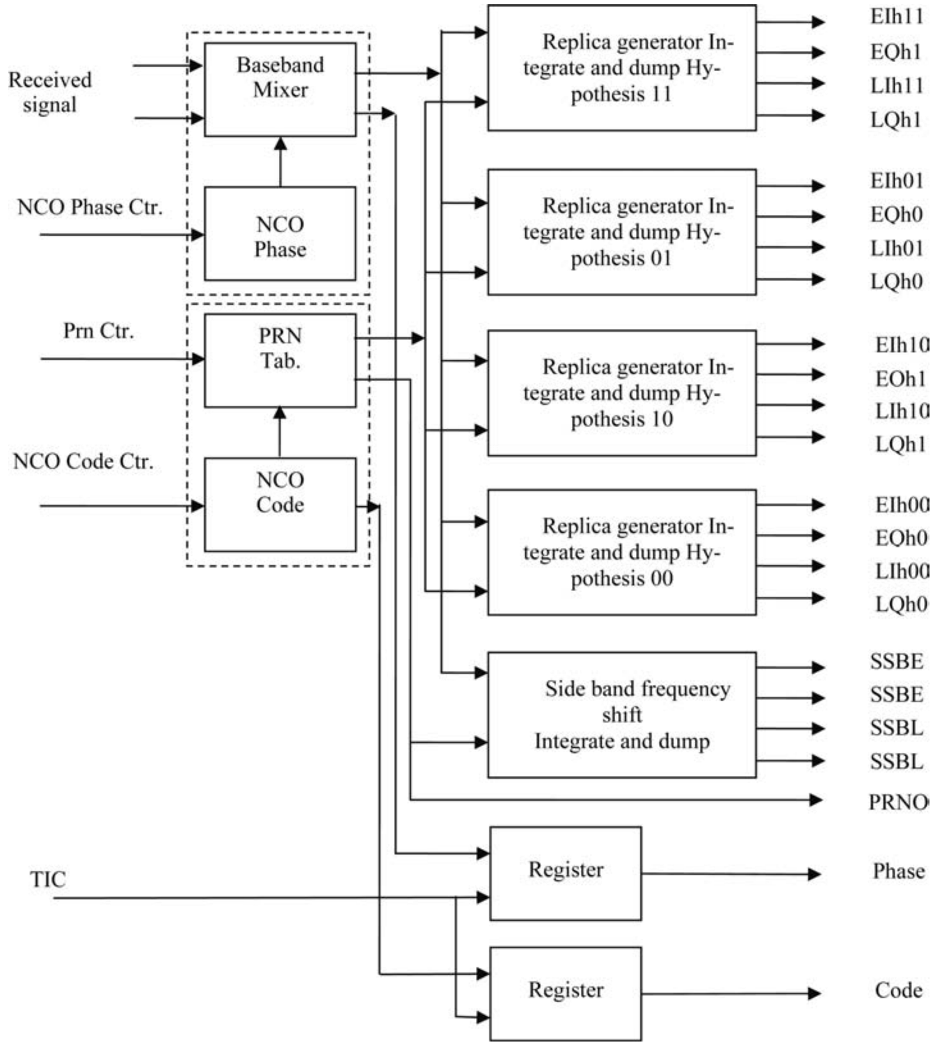

Figure 2. Galileo E5 correlator structure.

bits. The fifth branch supports final signal acquisition, secondary code synchronization and also verification of the correct correlation peak tracking. This correlate branch processes only one signal component of the Galileo E5 signal.

4 CORRELATOR VERIFICATION

The proposed Galileo E5 correlator was verified by the live Giove A and Giove B signals and on the Galileo E5 signal generated by a signal generator. This signal is processed by the GNSS software receiver EGR 2 which has been developed at the Czech Technical University since 2000.

The block diagram of the receiver is drawn on Figure 3. The Galileo signal is received by the wide-band GNSS antenna equipped with the low noise high dynamic range amplifier. The next receiver block is a selective amplifier which splits partial GNSS signals on L1 (E1), L2 and E5 (L5) frequencies. The E5 signal is processed by a zero intermediate frequency receiver. The base band signal is digitalized and processed in Virtex 5 FPGA. The measured data is sent via Ethernet to the PC workstation for further processing.

The proposed Galileo E5 correlator was developed in Matlab Simulink using with Xilinx System Generator Toolbox. The correlator is controlled by the embedded processor also integrated into the FPGA.

5 EXPERIMENTAL RESULTS

This paragraph presents preliminary results of the implemented Galileo E5 correlator. The results were obtained by the receiver with not fully optimized DLL and a PLL tracking loops. The signal was received by the experimental antenna system equipped with a

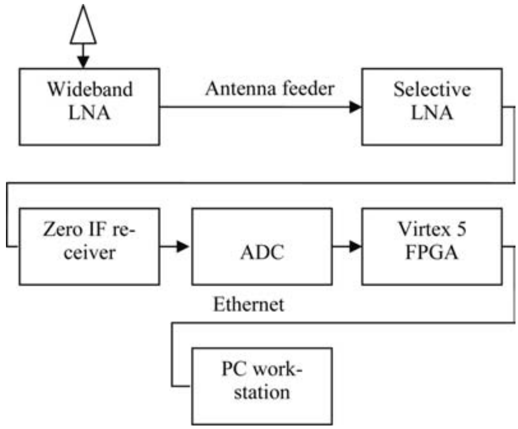

Figure 3. EGR 2.

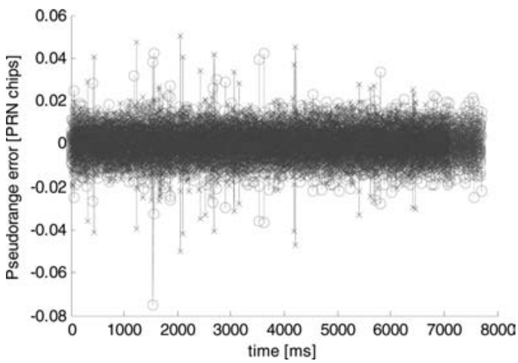

Figure 4. Code tracking error (× – Giove A, ○ – Giove B).

helical RF filter. The noise figure of this antenna is proximately 5 dB.

The plot of the pseudo range error and the carrier phase error for the Galileo Giove A and Giove B satellites are plotted on Figures 4 and 5. The standard deviation of these errors is in Table 1.

We are going to repeat these experiments with higher performance GNSS antenna based on PHEMT LNA with a noise figure 1 dB and a higher performance selective LNA populated with the low insertion loss and low distortion coaxial resonators filters and with the fully optimized DLL and PLL tracking loops. We believe that we will reach better performance.

6 CONCLUSIONS

This paper presents the Galileo AltBOC E5 signal characteristics and on their base proposes the structure of the optimal Galileo E5 correlator for the AWGN

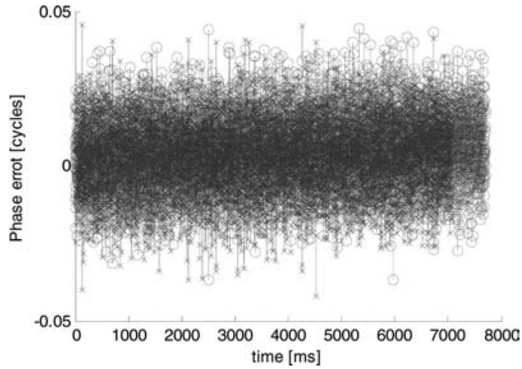

Figure 5. Phase tracking error (× - Giove A, ○ – Giove B).

Table 1. Code and phase tracking error.

Satellite	Giove A	Giove B
Standard deviation of code tracking error [m]	0.202	0.204
Standard deviation of phase tracking error [mm]	2.83	2.81

channel. The structure of the proposed correlator is complicated due to the non linearity of the AltBOC modulation of the navigation message bits which requires to calculate the cross correlation function between the received signal and the replica for four hypotheses.

The developed correlator was tested in the software receiver on the live Galileo signals with the promising preliminary results. The final test is planed to realize with the higher performance reception antenna and with the fully optimized PLL and DLL tracking loops.

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3.6 The implementation of the EGNOS system to APV-I precision approach operations

A. Fellner
Silesian University of Technology, Gliwice, Poland

K. Banaszek
Polish Air Navigation Services Agency, Warsaw, Poland

P. Tróminski
GNSS-Consortium, Poland

ABSTRACT: First in the Poland tests of the EGNOS SIS (Signal in Space) were conducted on 5th October 2007 on the flight inspection with SPAN (The Synchronized Position Attitude Navigation) technology at the Mielec airfield. This was an introduction to a test campaign of the EGNOS-based satellite navigation system for air traffic. The advanced studies will be performed within the framework of the EGNOS-APV project in 2009. The implementation of the EGNOS system to APV-I precision approach operations, is conducted according to ICAO requirements in Annex 10. Definition of usefulness and certification of EGNOS as SBAS (Satellite Based Augmentation System) in aviation requires thorough analyses of accuracy, integrity, continuity and availability of SIS (Signal in Space). Also, the project will try to exploit the excellent accuracy performance of EGNOS to analyze the implementation of GLS (GNSS Landing System) approaches (Cat I-like approached using SBAS, with a decision height of 200 ft). Location of the EGNOS monitoring station Chelm, located near Polish-Ukrainian border, being also at the east border of planned EGNOS coverage for ECAC states is very useful for SIS tests in this area. According to current EGNOS programmed schedule, the project activities will be carried out with EGNOS system v2.2, which is the version released for civil aviation certification. Therefore, the project will allow demonstrating the feasibility of the EGNOS certifiable version for civil applications.

The following article provides a overview of the performance of EGNOS SIS (PRN 120) as observed at EGNOS 7 days over a period of 168 hours from 19 of November 00:00 until 26 of November 23:59 with a Septentrio PolaRx 2 receiver, during the observed period of 168 hours at EGNOS CHELM. Smoothing was set to 100 seconds.

This First Glance Report is generated with Pegasus 4.2 and presents the following performance characteristics:

- **Sample validity**: Valid samples are all the samples that are present in the data and are not considered to be affected due to logging or processing tool problems
- **Accuracy** statistics: calculated for horizontal and vertical positioning errors separately.
  - For the **measured accuracy**, the samples are taken directly from the horizontal and vertical errors as computed by PEGASUS.
  - For the scaled accuracy, every sample is scaled with a ratio of AL/PL(i) before taking the 95th percentile.
- User **Availability** percentiles for the different PA operations: determined by dividing the number of samples that are available for an operation by the total number of valid samples
- Number of **discontinuity events** within the period: the total number of discontinuity events for a given operation.
- Number of **Integrity** events within the period: the total number of integrity events. The Misleading Information (MI) events are determined based on samples with XPE > XPL. The Hazardous MI (HMI) are counted according to XPE > XAL > XPL for each operation.

All values that exceed a certain required threshold are presented in red.

For more information refer to the FGA Performance algorithms document.

Table 1. SIS analyze.

Site	[ANALYZE] EGNOS CHELM 7 days							Date	27/11/2008	
Location	Lat:	51.130		Lon:	23.480			Alt:	254.70	
Receiver	Septentrio PolaRx 2			Soft-ware	Pegasus 4.2			PRN	120	
Data set	Duration	Start	Stop	Ex-pected	Total	SBAS Msg		Valid	Valid(%)	
1 Hz	168h00	00:00	23:59	604800	604788	604285		604428	**99.94%**	
Results per operation										
	Operation	**APV-I**			**APV-II**			**CAT-I**		
	HAL/VAL	40 / 50			40 / 20			40 / 12		
Accuracy (m)										
		Meas.	Scaled	Req.	Meas.	Scaled	Req.	Meas.	Scaled	Req.
HNSE (95%)		**1.71**	6.92	16	1.72	7.03	16	1.72	7.72	16
VNSE (95%)		**1.69**	5.46	20	1.63	2.23	8	1.53	1.60	4
Availability (%)										
Valid EGNOS Solutions	603370	**597696**			510339			62104		
Minimum Required		99%			99%			na		
Availability		98.886%			84.433%			**10.275%**		
Continuity										
Events		345			3120			**7838**		
Integrity										
	MI	HMI APV-I			HMI APV-II			HMI CAT-I		
Total	**0**	0			0			0		
Horizon-tal	**0**	0			0			0		
Vertical	**0**	0			0			0		

Table 2. PL and APV-I statistics.

Protection level statistics

	99%	95%	50%	mean	std deviation
HPL	**34.81**	22.99	10.24	11.89	5.21
VPL	**35.66**	24.43	15.40	16.39	4.67

APV-I Position error statistics

	Samples	**Mean**	**RMS**	95%	std deviation
HPE	**597696**	1.10	1.16	1.71	0.35
VPE	**597696**	0.76	0.92	1.69	0.51

1 SIGNAL IN SPACE ANALYSIS

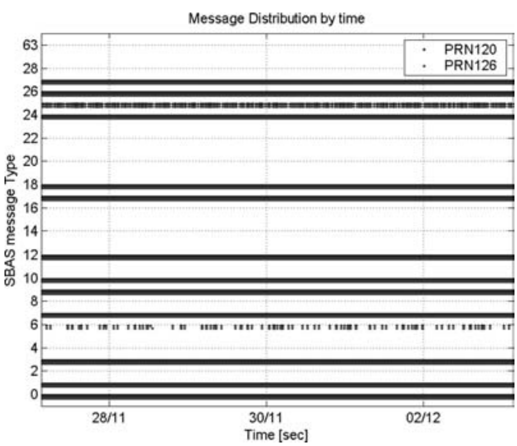


Figure 1. Message Distribution by time.

1.1 *Message types distribution*

Table 3. Message type counter.

	PRN 120		PRN 126	
SBAS MT	Number	%	Number	%
MT 0	150905	24.97	150839	24.97
MT 1	9396	1.55	9393	1.56
MT 2	0	0.00	0	0.00
MT 3	150865	24.97	150806	24.97
MT 4	0	0.00	0	0.00
MT 5	0	0.00	0	0.00
MT 6	590	0.10	585	0.10
MT 7	9397	1.56	9392	1.55
MT 9	9396	1.55	9393	1.56
MT 10	9396	1.55	9393	1.56
MT 12	3764	0.62	3762	0.62
MT 17	3764	0.62	3763	0.62
MT 18	18819	3.11	18814	3.11
MT 24	150869	24.97	150807	24.97
MT 25	550	0.09	550	0.09
MT 26	82811	13.70	82772	13.70
MT 27	3763	0.62	3763	0.62
MT 28	0	0.00	0	0.00
MT 62	0	0.00	0	0.00
MT 63	0	0.00	0	0.00
Total	604285	100.00	604032	100.00

1.2 *Message type 6 analysis*

This figure shows the number of occurrences for consecutive MT6 broadcasts (1, 2, 3, 4 or more repetitions). A normal alert consists of four consecutive MT6 messages, while single occurances indicate CPF switch-overs.

Table 4. Message type 6 repetitions.

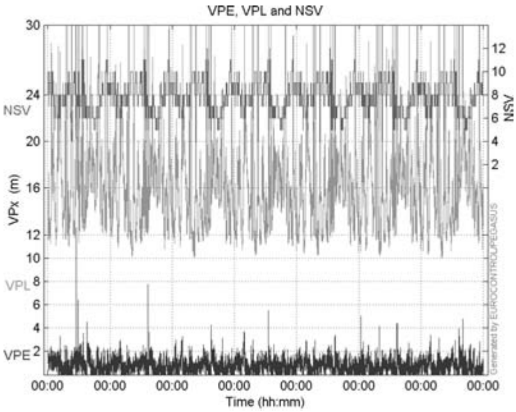
Message Type 6 repetitions					
	Single	Double	3x	4x	>5x
PRN 120	1	0	1	145	1
PRN 126	1	0	1	145	0

2 POSITION SOLUTION ANALYSIS

2.1 *Position errors and protection levels*

All plots have fixed scales that represent nominal behaviour. When the performance does not fit properly within these scales further detailed investigations are needed.

2.2 *Position solution plots*



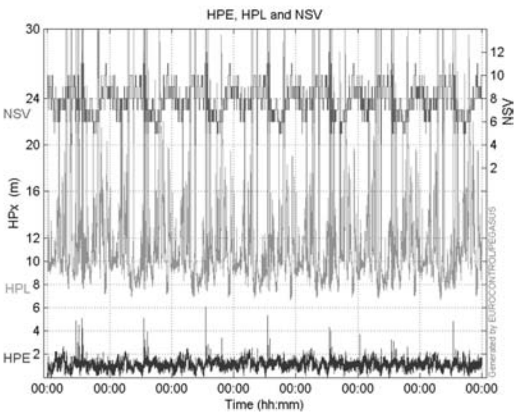


Figure 2, 3. Horizontal and vertical Error, Protection Level and NSV over time.

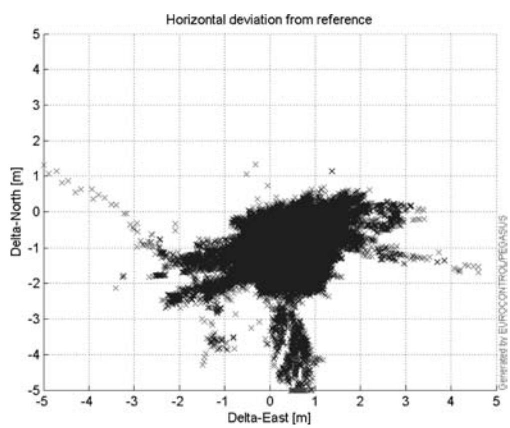
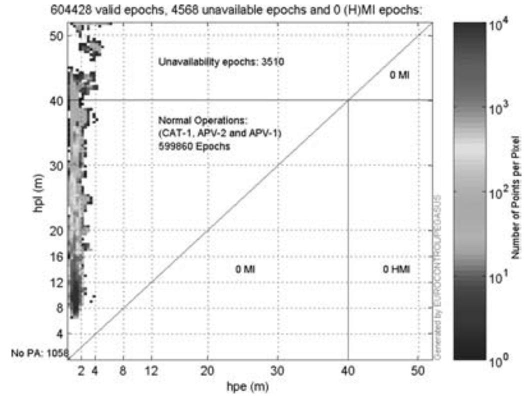


Figure 4. Scatter plot of horizontal deviation from reference position.



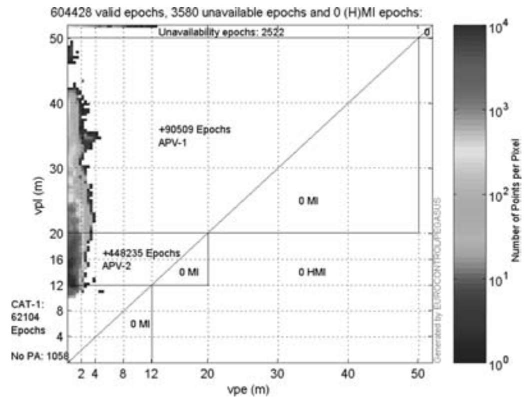


Figure 5, 6. Horizontal and Vertical Stanford graphs.

2.3 *APV-I statistics*

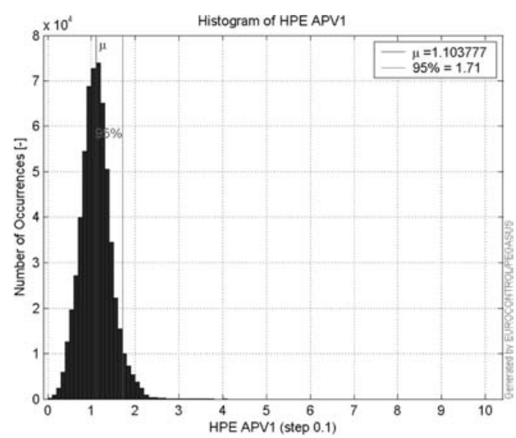
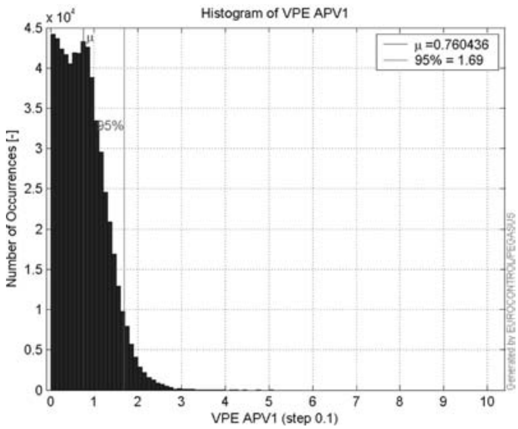


Figure 7, 8. Horizontal and Vertical position error distributions (epochs when APV-I available).



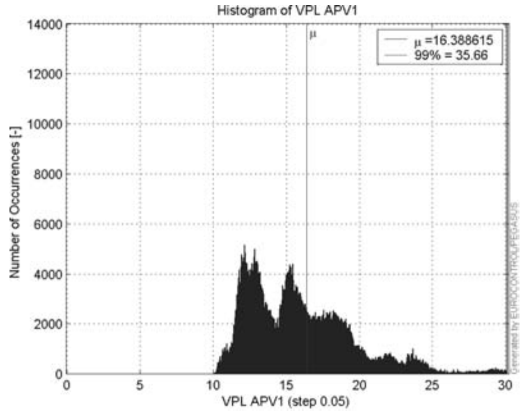
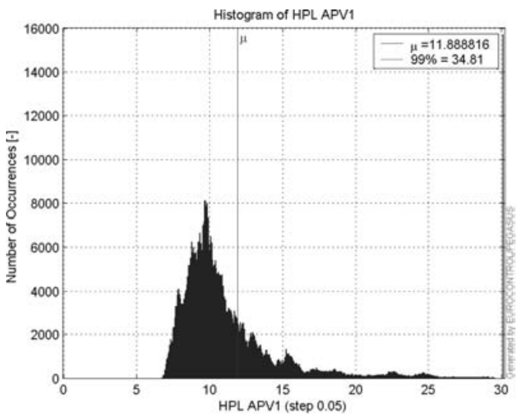


Figure 7, 8. Continued



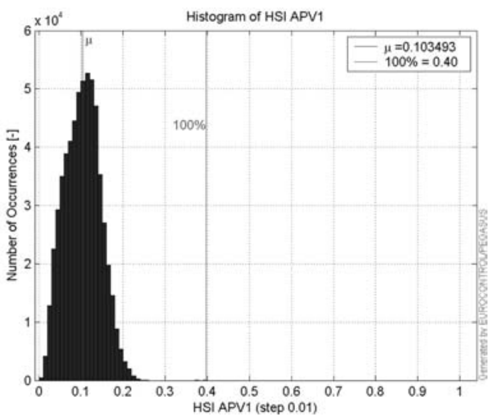


Figure 9, 10. Horizontal and Vertical protection level distributions (epochs when APV-I available).

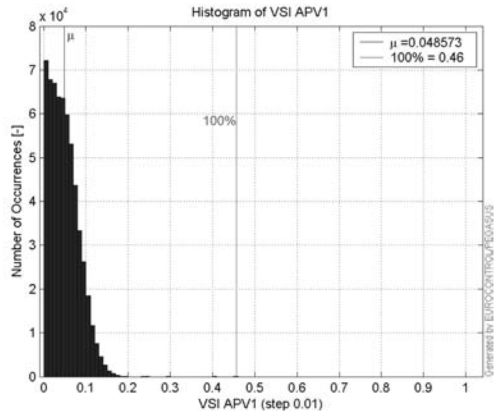


Figure 11, 12. Horizontal and Vertical Safety Index distributions (epochs when APV-I available).

2.4 *Integrity*

In case of a (potential) Misleading Information situation, this section will provide a list of all the epochs where there was an xPE/xPL ratio of more than 1 (real MI) or more than 0.75 (near MI).

2.4.1 *Integrity events*

There are no Integrity events in the data. The maximum Horizontal PL/PE ratio is 0.397273 and the maximum Vertical PL/PE ratio is 0.455981

The following table represents the most extreme epochs: Highest xPE/xPL ratio, Lowest xPL values and Highest xPE values.

Table 5, 6. Highest xPE/xPL ratio, Lowest xPL values and Highest xPE values.

Extremes							
	Epoch	HPE	HPL	HPE/HPL	VPE	VPL	VPE/VPL
max normHor	175329	3.59359	9.04564	0.39727	1.51378	10.8631	0.13935
max normVer	175331	0.16034	8.86431	0.01809	5.03754	11.0477	0.45598
max HPE	565906	6.07277	60.2411	0.10081	−1.57755	35.1706	0.04485
max VPE	385129	4.89637	52.9584	0.09246	−12.6208	140.124	0.09007
min HPL	78769	1.22757	6.67681	0.18386	0.71793	11.5757	0.06202
min VPL	287957	0.97835	6.78061	0.14429	0.06461	10.0249	0.00645

	HPE	HPL	HPE/HPL	VPE	VPL	VPE/VPL
Extremes	6.07277	6.67681	0.397273	−12.6208	10.0249	0.455981

2.5 *Cumulative Density Function*

The Cumulative Density Function (CDF) gives a good indication of the quality of the data in terms of over-bounding. Especially the trend towards lower probabilities becomes clear. The graphs should be read as follows:

- The Red dashed line indicates the ideal trend
- The vertical axis indicates the probabilities, the more data is available, the lower the graphs continue
- The horizontal axis indicates the quality of over-bounding.
- The data points are strictly not allowed to exceed the red-dashed line.
- However at the start they normally tend to exceed it, and this is acceptable as long as this is only for a small area at the beginning
- The steeper the trend of the data-points, the better.
  - A clear downward trend gives confidence that the over-bounding is sufficient.
  - A clear trend towards exceeding the reference (red-dashed) line is an indication of non over-bounding.
  - In case the trend is parallel and close to the reference, further investigation such as EVT is recommended.
  - A change(s) of the trend suggests that multiple system modes are present in the data. For detailed analysis these should be separated.

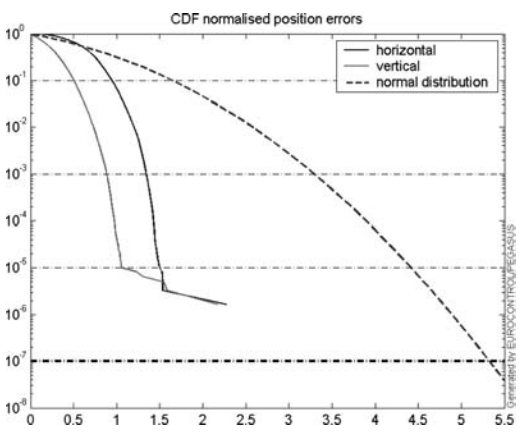


Figure 13. Horizontal and Vertical Position over-bounding in CDF.

2.6 *Continuity*

This section will provide a list of all the discontinuity events. In case there are more than 20 discontinuity events the tables are filtered to a maximum table length of 20. In case there still too many independent events, the table will not be displayed and further investigation is recommended.

The following table presents the discontinuity performance in more detail.

- All discontinuities regardless of duration (same as in firstglance)
- Long discontinuities lasting 3 or more seconds
- Independent discontinuities, lasting 3 or more seconds and after continuously available period of 15 or more seconds
- P(disc.): Continuity Risk determined by multiplying the continuity risk per epoch with 15 seconds
- P(slide): Continuity Risk determined with sliding window of 15 seconds

Table 7. Discontinuity in detail.

Discontinuity events					
	Valid	APV-1	APV-2	CAT-1	APV-35m
All	10	345	3120	7838	745
Long	9	40	173	257	49
Independent	7	27	103	67	27
P(disc.)	0.00017	0.00068	0.00303	0.01618	0.00069
P(slide)	0.00021	0.00206	0.01723	−9.35643	0.00371

2.7 *Discontinuity events for position solution*

Table 8. The following table presents all Position discontinuity events.

Position discontinuity events

#	Epoch	Duration	Stable period
1	379453	34	33493
2	387656	219	8169
3	387879	25	4
4	416940	160	29036
5	484425	171	67325
6	484600	84	4
7	70570	160	28709
8	109514	1	38784
9	201129	44	4466
10	242862	160	41689

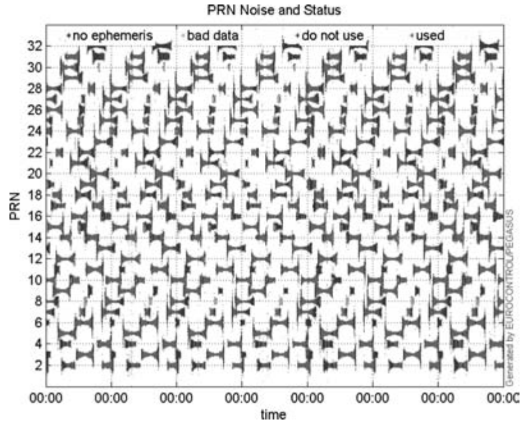
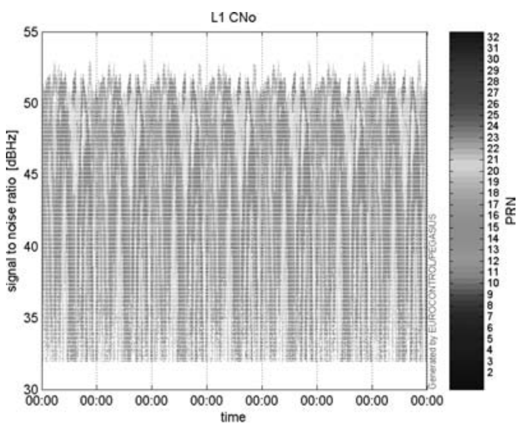


Figure 16. PRN Noise and Status.

3 RANGE DOMAIN ANALYSIS

3.1 *Signal quality and PRN Status*



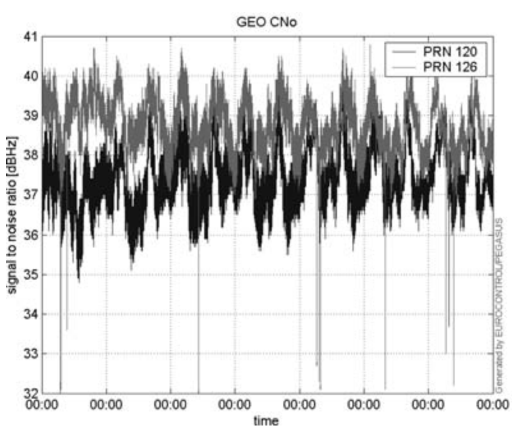
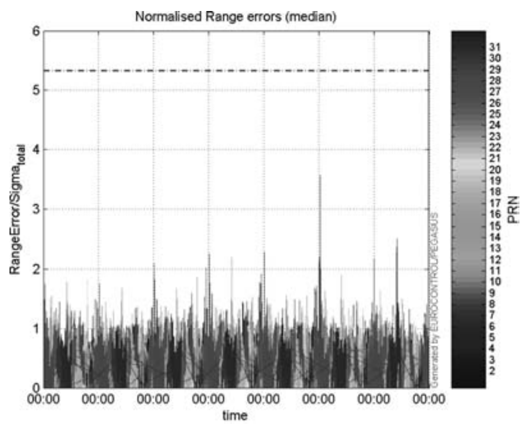


Figure 14, 15. Signal to Noise ratio.

3.2 *Normalised range error*



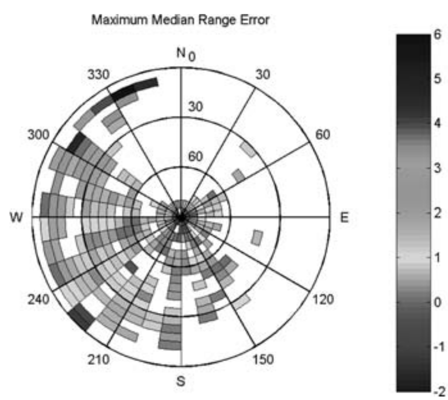


Figure 17, 18. Normalised range errors.

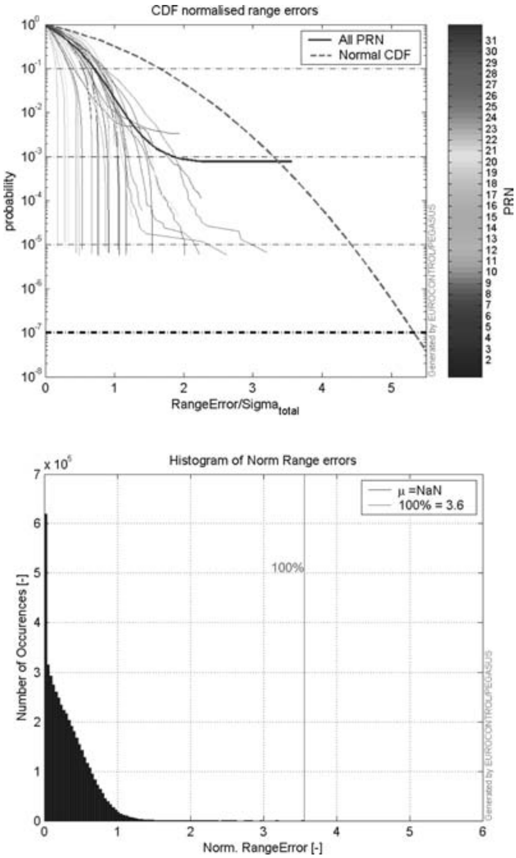


Figure 19, 20. Normalised range errors histogram and CDF.

4 CONCLUSION

From a GNSS applications point of view (GPS assisted in Europe by EGNOS) special importance parameters recorded by the receiver are: availability and continuity. Carried out measuring session shows that the EGNOS system in the current development phase isn't meeting requirements put for air applications. The preliminary assessment of the EGNOS system doesn't let categorize it as meeting APV requirements at the border of the EGNOS service.

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3.7 GPS-based vehicle localisation

A. Janota & V. Končelík
University of Žilina, Faculty of Electrical Engineering, Department of Control & Information Systems, Žilina, Slovakia

ABSTRACT: The paper describes the processor-based equipment designed for the purpose of traffic means localisation. Data transmission is realised through GSM modem as a standard component of GSM phones. Control station gets a data set from GPS receiver based on the given command and identification through SIM module. Data is used to determine exact time, transaction date, geographical position, instantaneous velocity as well as azimuth. After transferring data into digital map the operator can observe a place of traffic means. Transaction requires transmission of minimal data volume (ca 80 Byte) which is a minimal load for created mobile phone connection. The paper describes essential technical details characterizing the developed equipment and obtained experience.

1 INTRODUCTION

Data transmission using a small volume of data in mobile means is a relatively simple and mastered technology today. If the mobile means is equipped with a GSM modem and GPS receiver then the automatic means placed in a vehicle can respond to commands coming from the control centre. The paper presents results of the possible technical solution realized by the authors. The GPS receiver provides a data set that can be appropriately selected by the user. If one needs to know geographical position, time, date, velocity, course, then the GPS sentence with the GPRMC prefix may be used. Setting of the GPS receiver for reception of just the given sentence only simplifies problem solution. The transfer speed has been set to 19200 bps (for the M35 Siemens cell phone) corresponding to the GSM transfer speed (standardly set to 4800 bps).

2 OEM GPS RECEIVER AND NMEA PROTOCOL

One of the problems to be solved results from existence of two sources of data signal that are switched over by the automaton to one control center. If we want to activate corresponding automaton placed inside the vehicle, by default the modem must be set to GSM communication. Once the arrival message (for the sake of simplicity only one recommended and known symbol) has been evaluated the automaton switches over the communication channel to the GPS source. The GPS receiver works permanently despite data is not valid (analyzed by the user).

As mentioned before each GPS receiver generates a set of data ordered into so called sentences according to the NMEA protocol. This protocol provides data expressed in ASCII code that can be shown directly at computer monitor without any formatting. The user must set the serial link (RS232) to the transfer rate of the GPS receiver. The maximum speed of data update by GPS receiver is 1 second however the user may choose a longer interval (Černý & Steiner 2003).

Each GPS receiver sentence starts with the $ symbol. This flag helps to identify beginning of the sentence. Information content of the sentence follows the prefix GPRMC (Garmin). Individual data in the sentence is separated by the "," (comma symbol, in the ASCII code the value 2Ch). Particular data can be evaluated based on the number of these symbols. As an example we can choose 80 symbols of the GPRMC sentence including the flag. Thus a part of the sentence is stored in the memory of microcomputer. After switching the communication source back to the default state content of the given part of memory may be transferred to the control centre where transaction is being finished and obtained data processed. As a result we can find out if the vehicle goes in a required direction (according to the oriented map), is standing or moving, breaking the speed limit etc.

The GPRMC contains following information at first 80 positions:

– the $ flag, followed by
– GPRMC, followed by the 1st separator ","
– Time (given in UTC), followed by the 2nd separator ","
– Data validity, followed by the 3rd separator ","
– Latitude, followed by the 4th separator ","
– Half-world sign, followed by the 5th separator ","
– Longitude, followed by the 6th separator ","
– Half-word sign, followed by the 7th separator ","
– Velocity in knots, followed by the 8th separator ","

Table 1. Conversion of ASCII symbols to the displayable data set of the GPRMC sentence in the NMEA protocol.

	$	G	P	R	M	C	,	2
ASCII	24	47	50	52	4D	43	2C	32
	1	2	1	2	9	2	9	,
ASCII	31	32	31	32	39	32	39	2C
	A	,	4	9	1	5	.	6
ASCII	41	2C	34	39	31	35	2E	36
	0	7	,	N	,	1	2	3
ASCII	30	37	2C	4E	2C	31	32	33
	1	0	.	5	3	7	,	W
ASCII	31	30	2E	35	33	37	2C	57
	,	0	0	0	.	0	,	3
ASCII	2C	30	30	30	2E	30	2C	33
	6	0	.	0	,	1	1	1
ASCII	36	30	2E	30	2C	31	31	31
	1	9	8	,	0	2	0	.
ASCII	31	39	38	2C	30	32	30	2E
	3	,	E	*	6	8		
ASCII	33	2C	45	2A	36	38		

– Movement course (azimuth), followed by the 9th separator “,”
– Data, followed by the 10th separator “,”.

Numbers of symbols of particular data is not given intentionally since they may be different according to the type of GPS receiver.

The indicated procedure makes the technical solution possible with minimum requirements to programming environment of the automaton. In any case the GPS receiver must be configured according to GSM communication needs. For the GPS OEM receivers by Garmin there is a cost-free programme available that can be used to set individual parameters of the GPS receiver. As an example the GPS18 module can be mentioned. Running the file SNSRCFG.EXE the corresponding serial COM port is being set, interconnected to the GPS receiver (COMM preamble). The preamble contains two items: SETUP and CONNECT. Once the communication has been activated the programme is searching for the transfer rate of the GPS receiver which is indicated at the monitor showing gradually all transfer rates tested. When choosing the preamble CONFIG, two items are available: SENSOR CONFIGURATION and NMEA SENTENCE SELECTION. The items GET CONFIGURATION FROM GPS and SEND CONFIGURATION TO GPS are activated as soon as the communication link has been established using the command CONNECT. All sentence preambles generated by the receiver and repeated periodically within adjustable intervals are transferred to the computer using GET CONFIGURATION command. If all received parameters are in accordance with user requirements the programme run may be terminated (EXIT in the FILE menu).

More frequent requirement concerns about changing some GPS receiver parameters. If some of them are different from intended the preamble SENSOR CONFIGURATION can be chosen and data proposed according to the planned purpose. Number and type of GPS receiver sentences may bet set through the preamble SELECT SENTENSES. Data prepared in this way can be sent to the GPS receiver using the preamble SEND CONFIGURATION TO GPS as the last step of the configuration process. The chosen options can be re-called by the preamble VIEW, item NMEA TRANSMITTED SENTENCES when the GPS receiver generates data according to new conditions. Newly established parameters are kept in the GPS receiver even after disconnecting the power supply.

If parameters of the GPS receiver cannot be modified or the GPS receiver is made by a different producer (G symbol in the GPRMC preamble means Garmin) the automation programme must be adapted in the following way. The transfer rate is standardly set to 4800 bps. The user must respect this fact and adapt the communication transfer rate to new conditions. If the receiver repeats sending more sentences of the NEMA protocol the programme for receipt of required data must be adapted. If we insist on checking the sentence check-sum (always generated by the GPS receiver) this is also possible at the expense of receiving the whole sentence. If data is to be validated just at the first reception, analysis of data following the second symbol “,” must be performed. The indication “A” confirms validity of data, all other combinations denote invalid data (most often “V”). All data from the GPS receiver are provided in the ASCII format. All newly defined parameters become valid after the reset (switch-off and and-switch-on) of the GPS receiver.

Software simulating the NMEA protocol seems to be a very effective tool for laboratory tests (without need to have the physically moving means with the GPS receiver and GSM modem). The program (GPSsimul) is licensed and its current version makes generation of 50 sentences of the NMEA protocol possible only. The simulator then continues generation of chosen protocol sentences but without sending them to the serial port (number as an optional parameter). Older versions of the programme worked without this limitation. In addition, the user can chose a type of the NMEA protocol sentence, geographical position, elevation above sea level, speed, course, repeat interval and check sum. The clock and date is taken over from the computer where the software is installed. The user defines time shift to UTC provided by the GPS. The software is also a very useful aid when solving problems related to dynamics of elaborated GPS data. Based on the given speed and course it generates relevant geographic coordinates that are transmitted via serial link. In this way one is able to substitute the real GPS receiver that usually does not work inside buildings and if provides some data it is of static nature. Figure 1 shows the software window with parameters modifiable by the user (indicated with arrows) or through the item SETUP SCREEN.

Figure 1. Control window of the GPSsimul programme.

The Figure 1 shows symbolically simulation of two types of sentences of the NMEA protocol (GPRMC and GPVTG) with a second data generating. The simulated speed is 5 knots with the course 201 degrees. Geographical data is generated and shown in the first line. Time data represents the UTC from 14 hours 09 minutes 34 seconds to 14 hours 09 minutes 40 seconds on date 26 Nov 2008.

Table 2. Sample of data listed by the automaton.

User	|	atdtXXXXXXXXX
Modem	|	CONNECT
GPS Rec.	|	**$GPRMC,070436,A,4912.1986,N, 01845.3541,E, 000.0,207.1,220108,003.3,E*7E**
Modem	|	OK (based on the + + + user-choice)
User	|	ath
Modem	|	OK

3 GSM MODEM

Work with the GSM modem assumes use of AT commands. Since there a lot of them only selected commands used in the application are mentioned here. Certain problems arise when working with GSM terminals. Transfer rate of the computer is 19200 bps (valid for the used Siemens M35 model). If we use the GSM modem it is also necessary to set activation of the SIM module from computer (instruction AT + SCIM = number of SIM card). After a certain time the activation is confirmed with OK, or according to the previous command ATV0(ATV1). All this is realized at the transfer rate 9600 bps via wireless GSM channels. Some GSM modems do not enable permanent setting of some parameters. In that case each interruption of power supply re-call default values that do not need correspond to our intention. It is mostly a matter of the S0 value of the modem register, specifying a number of rings after which the receiver circuits of the GSM are automatically activated. This value is usually set to 000 which indicates no response of the receiver to ringing. The transmitter then (after a certain time) indicates absence of the carrier frequency (or announces there is no answer). The value kept in the S0 register can be found using the preamble ATS0?. The answer given by the GSM modem is for example 000. It means that the modem will not answer the incoming call (Končelík 2004a, b).

Table 2 shows example of listing of actual data from the GPS receiver through the wired modem at the rate 19200 bps with requirement from the centre to send data via GSM wireless link. Table 2 also contains information about who creates the data, whether the user or the modem or the GPS receiver.

The first data following the comma (in the GPS sentence) declares UTC. Time shown in the upper table gives the value 7 hours, 4 minutes, 36 seconds. The 9th comma is followed by date declaring 22nd January 2008.

Data following the 2nd comma indicates validity of received data. Data following the 3rd, 4th, 5th and

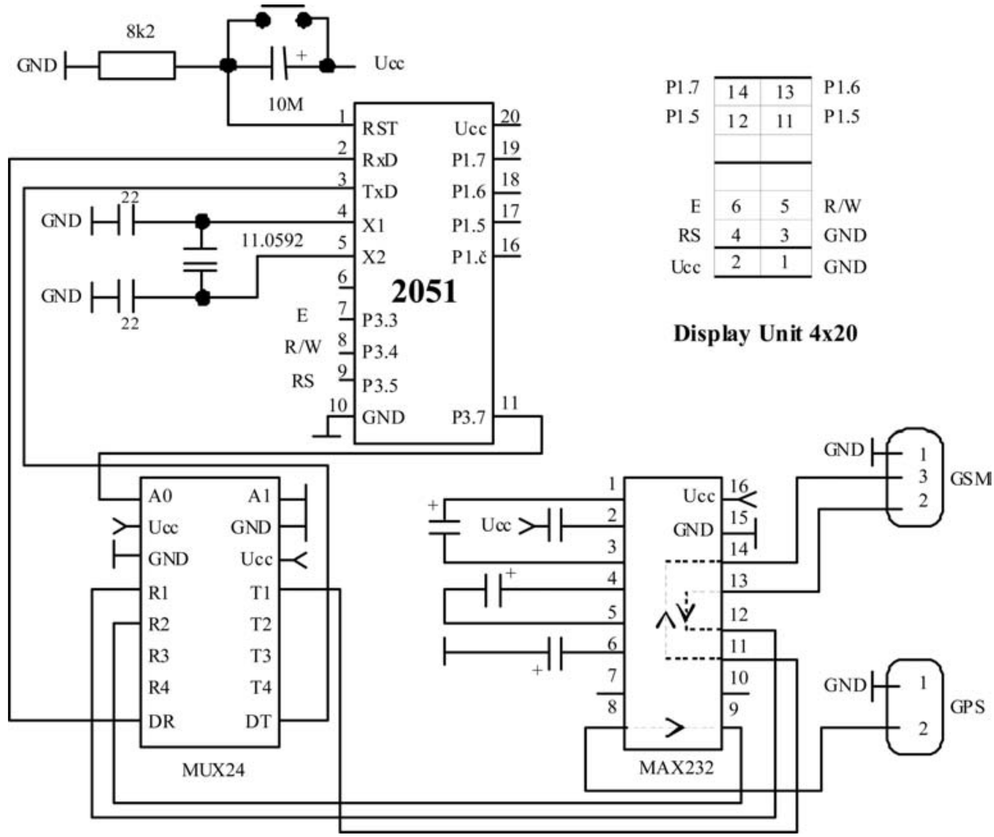

Figure 2. The scheme of the circuit for reporting the mobile means movement.

6th comma gives geographical data (latitude, North sphere, longitude, Eastern sphere). The 7th comma is followed by the speed in knots. Knot is a unit not used in Europe (1 kn = 1.852 km/h). The sample shows that the GPS receiver is not in movement. Next data represents course – in this case invalid due to zero speed. Data following the decimal point has no sense for this purpose. Data following the ∗ symbol gives check sum calculated as modulo 2 sum of data of the whole sentence from $ flag to ∗ symbol. Then there are used two symbols CR and LF that are not displayed (corresponding to the ENTER key). AT commands for GSM modem control are generated according to the type of modem.

4 CONTROL ALGORITHM AND PROGRAMME INTERPRETATION OF THE AUTOMATON EQUIPMENT

Programme for operation of GSM and GPS modules is configured by default to monitor serial link from the GSM modem periodically. If any symbol is received it is compared with the "F" symbol (a flag defined by the authors). In the case of positive result of comparison the built-in multiplexer switch over the signal to data receive from the GPS receiver. Then data at the serial link from the GPS receiver module is monitored searching for the flag "$" that represents beginning of NMEA protocol sentence. Other symbols received are being stored in operation memory of the microcomputer. Special attention is paid to observing number of commas, separating individual data of NMEA sentence having a different length. The 2nd separator is followed by data expressing validity of data of the sentence in question. If the programme evaluates the symbol "A" (ASCII symbol 41hex) next reading is continued, followed by storing data in operation memory of the microcomputer. Reading cycle can be performed in two ways. If we know amount of data in advance the reading cycle may be preset exactly. Otherwise, the programme is waiting for the symbol ending the sentence (0Dh, 0Ah). Then data flow is re-directed back to the serial link of the communication modem that is still in the CONNECT state, sending data from the operation memory of the microcomputer to the information source that initiated connection. If data from the GPS receiver appears at the monitor then connection is terminated with the sequence +++ (modem response is OK) followed by the command ATH (end of transaction). If we want to continue with getting new data in dosing interval under existing connection, the symbol "F" is sent again.

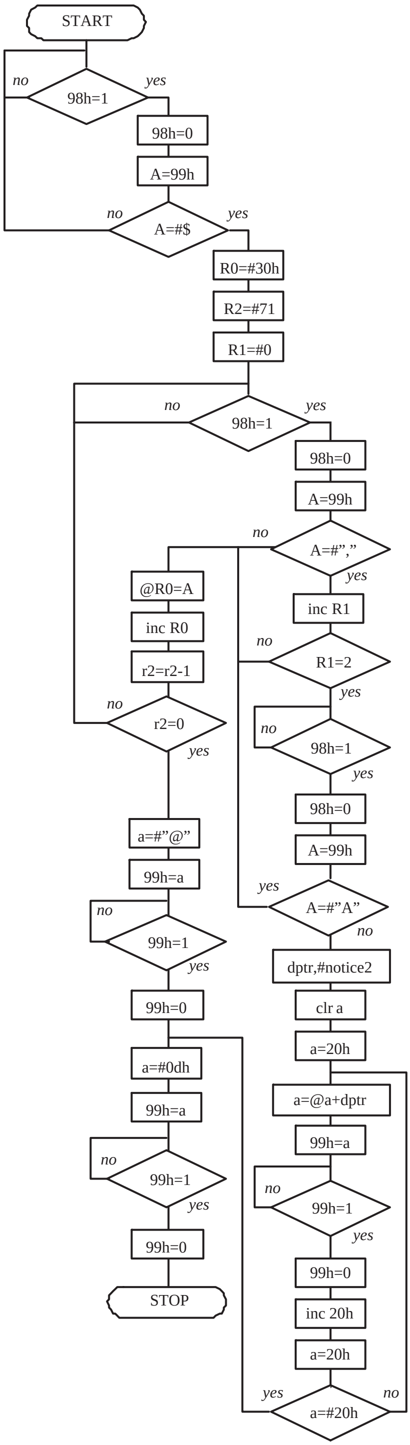

Figure 3. Flowchart for reading the GPRMC GPS sentence and for storing data from the address 30 h.

If the GPS receiver provides invalid data it is not transmitted but the title INVALID DATA is generated. Solution of such a situation depends on the user of stationary equipment. Either transaction may be

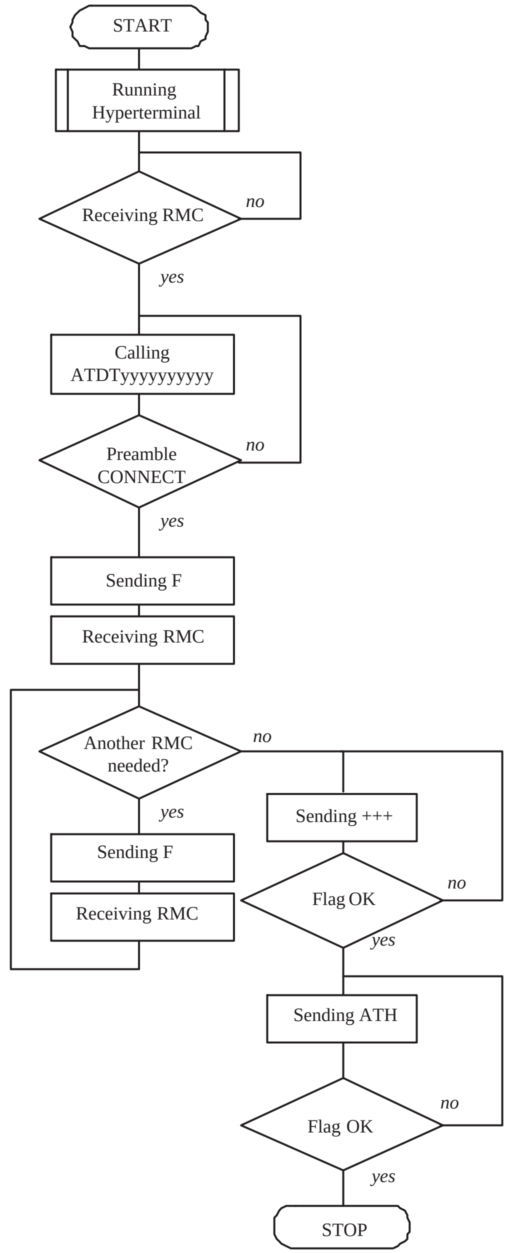

Figure 4. Control algorithm applied when received information about vehicle movement.

terminated or new data of the NMEA sentence may be asked by sending the “F” symbol. The problem of versatility of the application consists in the fact that each GSM communicator may have different parameters used to set its operation (what is not a problem in the control centre). In mobile means the required data must be pre-set in advance. Automaton for establishing connection to a selected phone number has no chance to use variant solution. Despite the number of instructions for establishing of pre-defined GSM connection

```
atdt0904901578
CONNECT 9600/RLP
GPRMC,140700,A,4913.5322,N,01847.0990,E,
023.0,275.9,130408,002.9,E*7A
OK
ath
OK
```

Figure 5. Example of application of described principle.

is relatively low the individual parameters must be set in advance according to the particular type of the GSM modem.

Figure 3 shows the flowchart describing the procedure of reading the GPRMC GPS sentence and storing data from the address 30h. Validity of is checked. In the case of invalid data the message INVALID DATA is communicated.

Technical solution is quite simple and in addition to GSM and GPS modules it requires a microcomputer, multiplexer, converter of TTL to RS232. More detailed information is out of scope of the paper. As far as the electronic circuitry is concerned equipment for vehicle localization is the same as for monitoring of the vehicle movement (Figure 2). The only differences are in software of the control unit.

Figure 4 shows the control algorithm describing situation when information about vehicle movement has been received. Both diagrams shown in Figure 3-4 correspond to the used processor Intel 51 (Valášek 1989). Usage of a different kind of processor may require changes in presented algorithms.

5 CONCLUSIONS

Getting data from GPS receiver makes possible to realize other applications that generate messages in the event that a vehicle is changing its position (compared with the original condition). Nonzero speed activates the GSM modem when the automaton performs calls and connecting to the centre with continuous service. Operator in this centre gets information in the form of actual sentence of the GPRMC and based on its parameters adequate measures can be taken.

Figure 5 shows the example containing particular data that can be used to find out where the mobile means is located, including its time and speed data.

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3.8
Effect of measurement duration on the accuracy of position determination in GPS and GPS/EGNOS systems

R. Bober, T. Szewczuk & A.Wolski
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: The authors have analyzed the effect of measurement duration on the accuracy of ship's horizontal (2D) position obtained by GPS and GPS/EGNOS receivers. Also, the influence of measurement duration on the mean position determination error in relation to a reference (geodetic) position has been examined.

1 MEASUREMENTS

In order to assess how measurement time affects the accuracy of horizontal position determination in GPS and GPS/EGNOS systems, more than thirty measurement sessions were performed. Observations during each session lasted at least 24 hours. The tests were carried out with two identical MiniMAX receivers made by CSI. The use of two receivers of the same type (with the same software) was aimed at eliminating possible errors that otherwise result from measuring instruments of various types. The GPS antennas were mounted on the antenna platform of the Maritime University of Szczecin. The antennas' positions were determined by geodetic methods.

The receivers were operated by using PocketMax_PC_Ver.2.2. software, which makes it possible to record data from MiniMAX receivers by PC computers. The data were recorded at 1 Hz frequency in NMEA-0183: $GPGGA, $GPGGL, $GPGSA, $GPGST, $GPGSV and $GPZDA formats. Observations lasted from November 2007 to November 2008.

2 MEASUREMENT RESULTS ANALYSIS

The assessment of measurement duration effect on the accuracy of horizontal position obtained by GPS and GPS/EGNOS systems based on registered data required current calculations, i.e. after each measurement, of the following quantities:

- mean latitude,
- mean longitude,
- circular error of position M (for $P = 0.95$),
- latitude shift of mean position relative to geodetic position ($\Delta\phi$ [m]),
- longitude shift of mean position relative to geodetic position ($\Delta\lambda$ [m]),
- distance between mean position and geodetic position (R [m]).

Table 1 presents calculation results for selected ten 24-hour measurement sessions.

Figures 1, 2 and 3, show the data from three sessions:

- changes of the circular error in time M (95%),
- changes of latitude shift of mean position in time relative to geodetic position ($\Delta\phi$ [m]),
- changes of longitude shift of mean position in time relative to geodetic position ($\Delta\lambda$ [m]),
- changes in time of mean position distance to geodetic position (R [m]).

Table 1. Ten 24-hour measurement sessions by GPS and GPS/EGNOS receivers.

	Measurement	Elevation	Measurement date	M(95%) [m]	$\Delta\phi$ [m]	$\Delta\lambda$ [m]	R [m]
1	GPS	20°	18.06.08	2.11	−0.73	−0.64	0.972
2	GPS/EGNOS	25°	19.06.08	29.17	−1.12	−0.58	1.262
3	GPS	20°	18.08.08	20.21	−0.58	−0.13	0.605
4	GPS	5°	19.11.08	1.88	−0.55	−0.80	0.973
5	GPS/EGNOS	5°	20.11.08	2.02	−0.66	−0.56	0.868
6	GPS/EGNOS	5°	21.11.08	2.54	−0.54	−0.61	0.733
7	GPS/EGNOS	5°	22.11.07	2.90	−0.48	−0.62	0.795
8	GPS	5°	25.11.08	2.94	−0.41	−0.60	0.725
9	GPS	5°	26.11.08	3.49	−0.33	−0.55	0.639
10	GPS	5°	27.11.08	3.09	−0.67	−0.63	0.913

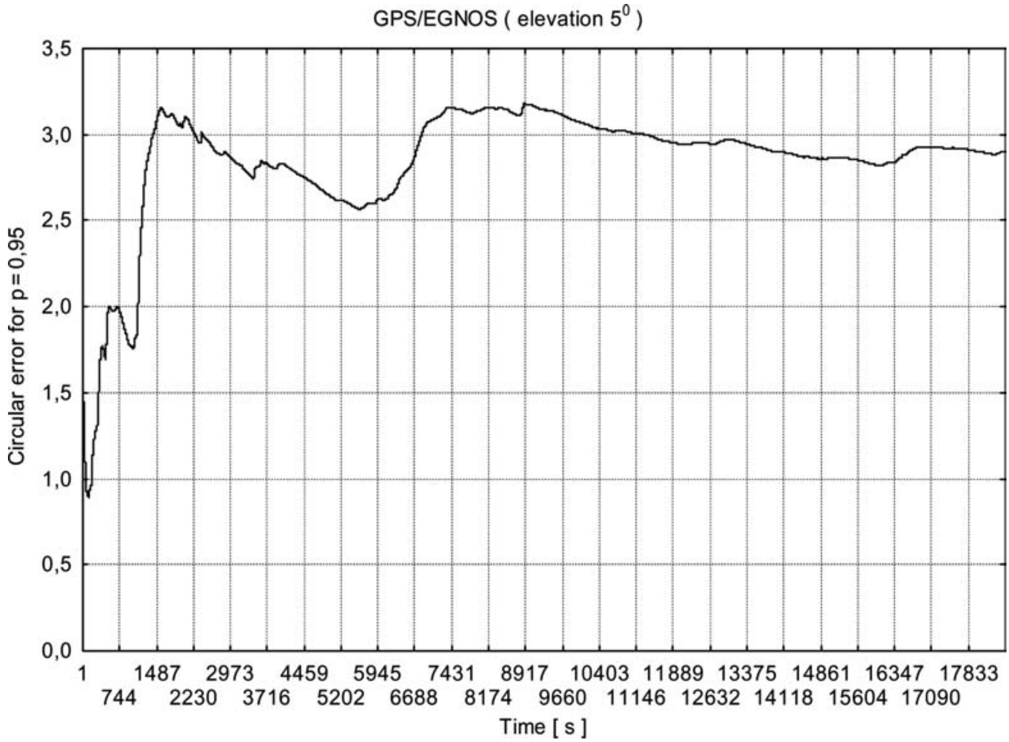

Figure 1. Changes of circular error after n seconds. Time scale × 5. Measurements of 22.11.2008.

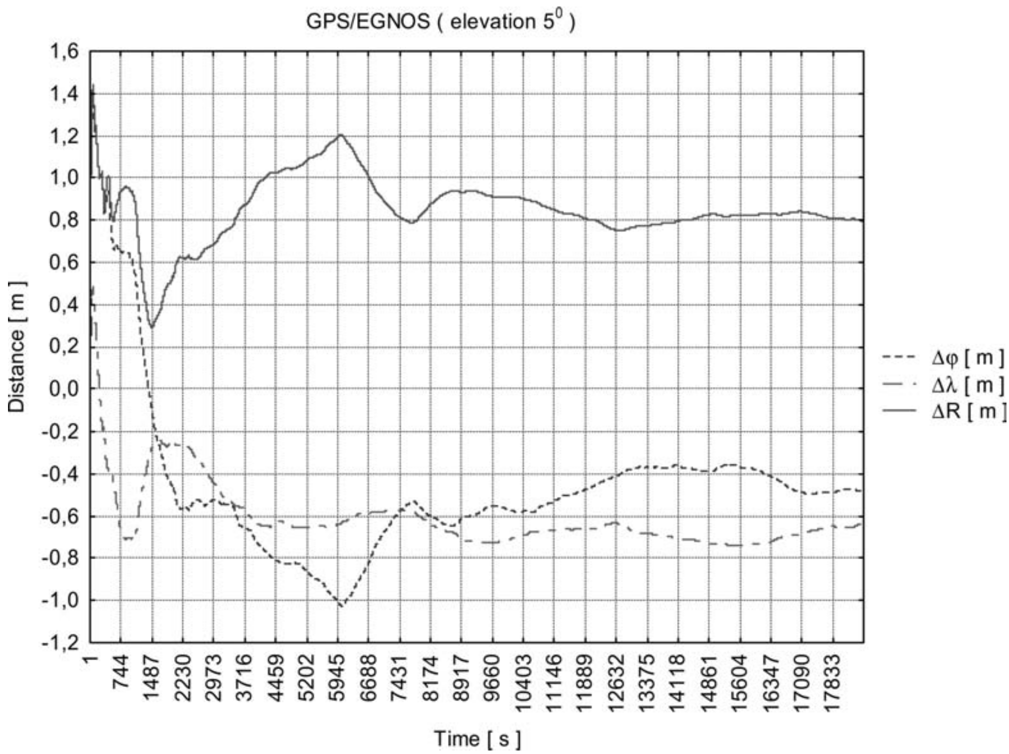

Figure 2. Changes of mean position shift after n seconds relative to geodetic position. Time scale × 5. Measurements of 22.11.2008.

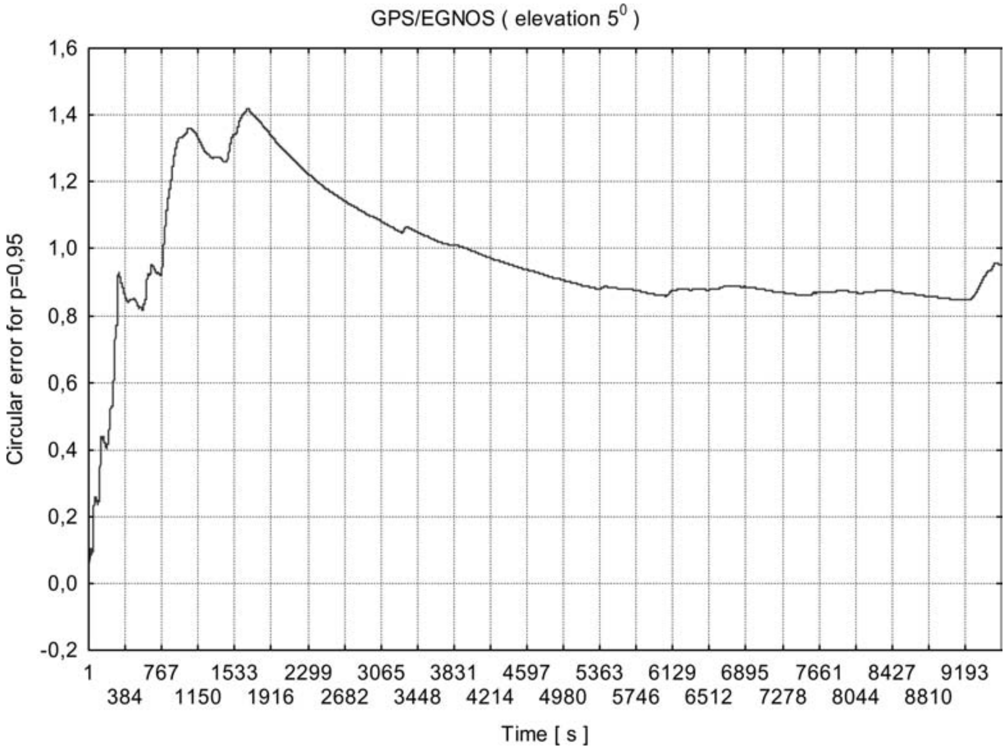

Figure 3. Changes of circular error after n seconds. Time scale × 5. Measurements of 23.11.2008.

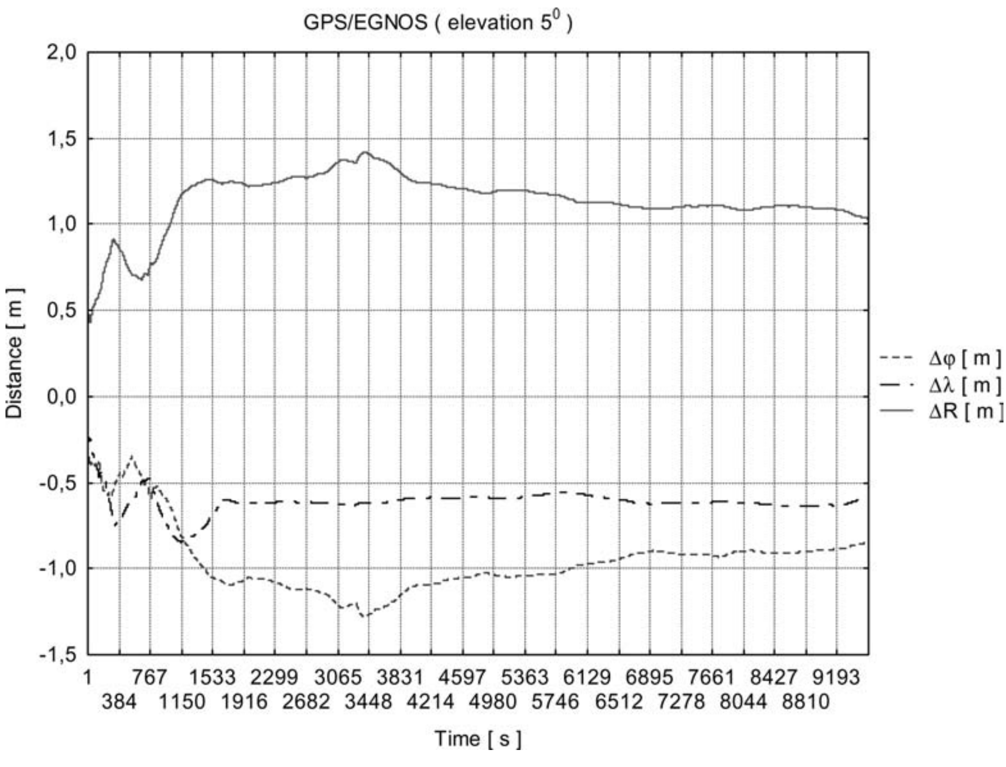

Figure 4. Changes in mean position shifts after n seconds relative to geodetic position. Time scale × 5. Measurements of 23.11.2008.

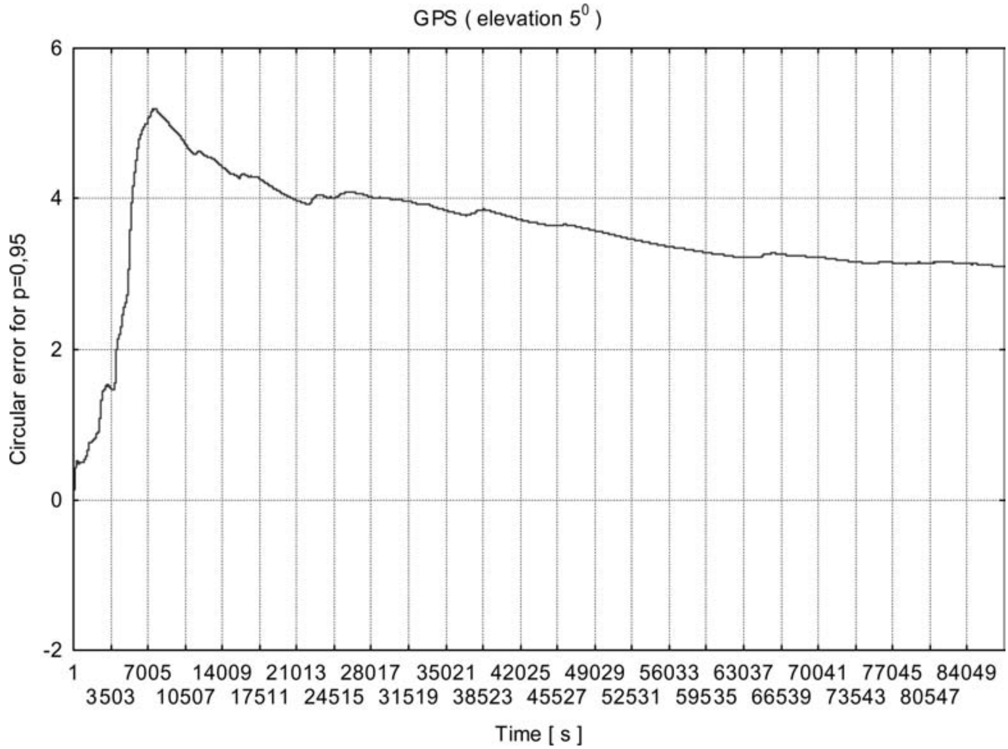

Figure 5. Changes of circular error after n seconds. Measurements of 27.11.2008.

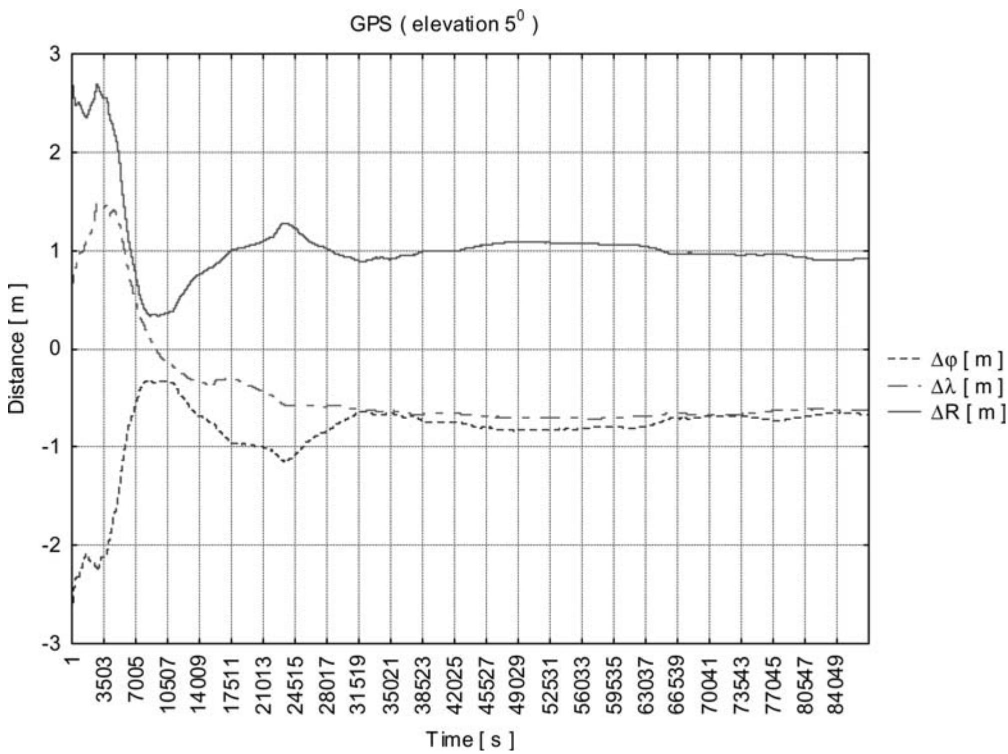

Figure 6. Changes of mean position shifts after n seconds relative to geodetic position. Measurements of 27.11.2008.

3 CONCLUSIONS

1. In the first stage of measurements (one hour) both the position error determined from current readouts of the receiver and the mean position shift relative to the geodetic position show significant fluctuations. The position shift exceeds two meters.
2. After about 12 hours the mean position relative to the geodetic one seems to be stable. After that time the distances between the mean position and the geodetic position do not change more than 19 centimetres.
3. Even if there occur major disturbances during the measurements (2nd and 3rd measurement series) the mean position for a long period of measurements does not differ significantly from the mean position obtained from undisturbed measurements. This refers to both GPS and GPS/EGNOS measurements.
4. The accuracy of positions determined for long measurement series is similar for GPS and GPS/ EGNOS systems.

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Chapter 4. Marine traffic control and automatic identification systems

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

4.1
Sustainability of motorways of the sea and fast ships

F.X. Martínez de Osés & M. Castells i Sanabra
Technical University of Catalonia, Barcelona, Spain

ABSTRACT: The European transport policy undertakes to enhance sustainability in transport in order to boost economic activities in the whole EU. The reduction of pollutant emissions and a better balance among modes of transportation to cut road congestion are the pillars of the above policy. These factors are encouraging public and private stakeholders to use the freight maritime alternative more extensively. Short sea shipping is considered the quickest way to reach sustainability. Another advantage of ships over trucks and trains is that vessels consume less fuel as a result of the relatively low speeds at which they travel. However, increasingly faster ships are in a position to compete with trucks, but the former's greater power demand and consumption rate result in higher pollutant emission levels which, in turn, lead to the loss of their environmental advantage over road transport. This problem is analyzed below.

1 INTRODUCTION

According to the mid-term review of the EU White Paper on Transport, Short Sea Shipping is expected to grow at a rate of 59% (metric tonnes) between 2000 and 2020. If we consider that the overall expected increase in both freight exchanges and volume is 50%, sea transport appears as one of the most feasible options to reduce traffic congestion on European roads. However, this alternative has not been definitely adopted because of technical, administrative and legal reasons. Moreover, society still regards maritime transport as a slow, inefficient mode since shippers do not yet offer the best value for money. Infrastructures need to be balanced by using tariff principles which reflect the exact external costs incurred by these infrastructures. Along this line of action, in 1998 the European Union published the White Paper on Fair Payment for Infrastructure Use: A Phased Approach to a Common Transport Infrastructure Charging Framework in the EU COM (1998) 466. This paper analyzes selected intermodal transport chains and pollutant emissions from different power output ships, and compares them with those generated by road transport. These emissions are then translated into environmental costs, based on existing quantification databases. In some cases, maritime transport proves to be a better alternative, justifying the granting of some kind of environmental bonus by the administration to promote the sea option. The paper concludes with a brief discussion on how to best implement this bonus to achieve a real balance between transport modes.

2 SCENARIO

In 1998, the European Union published the White Paper on Fair Payment for Infrastructure Use: A Phased Approach to a Common Transport Infrastructure Charging Framework in the EU COM (1998) 466, where "the user pays" and "the polluter pays" principles were established. It was initially suggested that dues charged on vehicles having a maximum payload of over 12 metric tonnes should be based on marginal infrastructure costs per kilometre and marginal urban congestion costs. The first tariff scheme for infrastructure use proposed in studies conducted in Europe like DESIRE (2001) and INFRAS (2004) was meant to be implemented in Germany in 2003 with an initial tariff of 0.17 €/km on all vehicle and truck units with a maximum loading capacity exceeding 12 metric tonnes passing through or delivering goods in Germany. However, after repeated delays, it was in 2005 that the scheme was launched with a tariff of 0.124 €/km. In 2007 the average rate increased to 0.135 €/km and tariffs were reviewed again in October 2008. As far as waste gas emissions are concerned, charges depend on the exact number of kilometers travelled on paid motorway sections, number of vehicle axes and engine class. Regarding pollutant emissions, in 1988 the European Parliament adopted the first Euro regulation, followed by Euro II, III and IV. Euro V and VI are increasingly stricter regulations on vehicle pollutant emissions, in particular particle emissions and nitrogen oxides (NOx) limits. Coming into force on 1st September 2009, Euro V establishes an 80% decrease in particle emission limits, which implies the need for future fitting of particle filters in vehicles. Euro VI will come into force in 2014 and impose limits of up to 68% of current levels on oxides. Maritime transport emissions are mainly regulated by the MARPOL Convention and some specific European regulations. The new directives concerning SO_2 and NO_x maximum emission levels aim to reduce these chemical compounds, which will be the weak point of maritime transport in the future. Of all modes of transport, the maritime one is responsible for the largest amount of SO_2 emitted into the atmosphere, only to be compensated by the use of low sulphur content fuels or exhaust gas cleaning systems. However, sulphur emissions from maritime transport account for 6% to 12% of total anthropogenic emissions only (Chengfeng 2007). Despite this scenario, in 2000 about 44% of total NOx emissions into the atmosphere in Europe were attributable to road transport and 36% to maritime transport (TERM 2002). Road transport is the main source of CO_2 emissions, contributing 91.7% of total EU transport greenhouse gas emissions. When including sea shipping in a breakdown of transport-related CO_2 emissions, it appears that in Europe maritime transport accounts for only about 6% of total greenhouse gas emissions, which explains the interest in reducing the share of road transport. Annex VI to the MARPOL Convention and the NOx technical code amendments were approved at the Maritime and Environment Protection Committee (MEPC) 58th session (October 2008), following the draft amendments on prevention of air pollution from ships agreed by the IMO Sub-Committee on Bulk and Liquid Gases (BLG) at its 12th session, held in February, and further agreed at the MEPC 57th session (April 2008).

2.1 *Environmental credentials of sea transport*

Maritime transport is one of the least pollutant modes. Additionally, it contributes to the reduction of traffic congestion, accidents and noise costs on European roadways (European Commission 2001). This justifies support actions to intermodal chains with marine sections including short sea shipping links as a way to reach more sustainable mobility within Europe. Nevertheless, a transport policy based solely on tariff measures will not provide the desired modal shift because users must see alternative transport modes as an efficient and quality choice. All administrative bodies should work cooperatively to improve intermodal infrastructures such as port and rail intermodal links or to simplify or speed up all document dispatch processes in maritime transport.

3 STUDY OF THE MARINE ALTERNATIVE

Due to patent medium-term rail transport limitations generated by the lack of coordination among all involved countries in terms of investment, mutual recognition of engineering licenses, unification of signal systems and standardization of electrical power distribution systems, short sea shipping is considered the best short-term option. The concept of short sea shipping is defined in the COM (1999) 317 "The Development of Short Sea Shipping in Europe" final document as the *transport by sea of goods and passengers, between ports geographically placed in Europe or between those ports and other ones located in coastal countries of the closed seas surrounding Europe*. This means that this mode of transport integrates the following aspects: roll on roll off traffic, general cargo traffic including containers, liquid and solid bulk and even neobulk traffic, passenger transport and feeder services.

Table 1. Routes obtained from the ANTARES study. Source: own data.

	Origin		Destination	
Route	Origin	Port	Port	Destination
Route 1	Madrid	Valencia	Naples	Naples
Route 2	Barcelona	Barcelona	Civitavec.	Rome
Route 3	Alicante	Alicante	Genoa	Milan
Route 4	Burgos	Tarragona	Genoa	Milan
Route 5	Zamora	Gijon	Hamburg	Berlin

Table 2. Emission rates for diesel Euro IV road and sea transport. Source: own, based on ICF model from REALISE, 2005.

	Road	Short Sea Shipping
Emitted gases	Euro IV (g/Kg fuel)	Improved (g/Kg fuel)
SO_2	0.114	30
NO_x	28.125	19.36
CO	5.75	8.1
Nm-VOC	2.316	2.466
PM	0.45	6.84
CH_4	0.095	0.099
CO_2	3,323	2,853
S	0.05	15

In this sense, all selected target routes, i.e. the five most efficient in INECEU (2005) and ANTARES (2007) studies, leave from Iberian Peninsula ports and have different destinations in Western Europe (Table 1).

Keeping in mind the above intermodal routes, the following criteria were used in our study:

1. Costs were divided into two main categories: external environmental costs, derived from local air pollution, global warming and noise pollution, and external non-environmental costs, derived from accidents and traffic congestion.
2. To evaluate the impact of the evolution of transport-related emissions, the scenario considered is a future hypothetical improved condition where future stricter regulations, like Euro IV, are applied to road (in force as of 2006 for new trucks and shown in table 6) and maritime transport, resulting in a 10% decrease in all current emissions, except for S, SO2 and NOx.
3. The cargo capacities of the selected Ro/Pax ships are considered, bearing in mind that they are real ships serving short sea shipping traffics in SW Europe. The three ships are an example of each speed group: conventional Ro/Pax vessels are represented by ship A, fast Ro/Pax vessels by ship B and high speed craft by ship C (Table 3)

Table 3. Main particulars of selected ships. Source: own, based on shipping company information.

	Conventional	Fast Conventional.	HSC
Particulars	Ship A	Ship B	Ship C
Type	RoRo/Pax	RoRo/Pax	Ro/Pax
DWT (Tm)	13274	5717	1076
GT	25058	23933	8089
Speed (knots)	18	27	40
Capacity (l.m.)	2600	1700	450
Trailers (19.5m)	133	97	23
Cars (units)	124	100	123
Passengers	500	1400	1291
Power (kW.)	24000	31680	32800

Table 4. Hourly consumption based on engine load and power. Source: own data.

	Speed	Consumption (Tm/hour)	
Type of ship	In knots	80% MCR	20% MCR
Conventional	20	3.84	0.96
Fast conventional	27	8.068	2.017
High speed craft	40	5.25	1.312

(Martínez de Osés & Castells 2008). Cargo capacity was calculated dividing the ship's total linear capacity by 19.5 meters (European Commission 2002), including the number of trucks (assumed FEUs) that the ship is capable of carrying. Cargo is measured in FEU (very close to trailer length) as it is the common unit of freight in sea and road legs, assuming the container to be filled to 60% of its full capacity (Martínez de Osés & Castells 2008).

4. The main engine specific fuel consumption rate is strongly affected by the installed propulsion systems, such as engine, gear, shaft and propulsion arrangements. Nevertheless, modern diesel engines use half the fuel consumed daily by old inefficient steam engines with the same power outtake (Endresen 2007).

   Although the total fuel consumption rate depends on the engine's maximum output, the average power is assumed to be 85% of MCR (Maximum Continuous Rate) of installed power. However, the average main engine load and speed vary dramatically for different ship types. Some authors have reported an average load of 80% MCR based on statistical data. For example, bulk carriers tend to have slightly lower average values (72% MCR) than tankers (84% MCR). Accordingly, load can range from about 60% MCR up to 95% MCR for the analysed ships (Floedstroem 1997). For our purposes, engine load was fixed to 80% of engine load when sailing and 20% for time spent at ports due to operations (Endresen 2007).

Table 5. Total external costs of the unimodal or sea-only intermodal solutions, taking the 200 g/h kW consumption rate for the Ro/Pax ships A, B and C in route 1 (Source: own, based on pricing costs from REALISE, 2005).

	Potential saving	Potential saving
Type of ship	€/FEU	€/FEU × km
Conventional	310.9	0.1477
Fast conventional	−16.08	−0.0076
High Speed Craft	−1,542.97	−0.733

5. The emission factors considered in our study are taken from the REALISE database. The advantage in CO2 emission factors in maritime transport lies in that ships consume less power than trucks to carry the same amount of cargo. However, as ship speed increases, the difference can be negligible and even negative. Additionally, because of the sulphur content of marine fuels, sulphurous emissions are still the weak point of maritime transport. A global average of 2.5% sulphur content is assumed, ranging from 0.5% for distillates to 2.7% for heavy fuel. We must emphasize that high-viscosity heavy fuel tends to have higher sulphur values than low-viscosity fuels. At this point, the question arises whether it is still feasible to propose an environmental bonus for trucks boarding a ship as ships have lesser pollutant effects per tonne and kilometre travelled than trucks.

4 PRELIMINARY RESULTS

Conventional ships are the most efficient type as far as pollutant emissions are concerned because they have the lowest consumption rates but also the lowest developed speed. Table 5 compares external cost savings of each ship type at only 60% of cargo capacity with those of road-only transport resulting from road distance not being covered.

These external cost savings could justify the proposal of an environmental bonus to encourage freight transport companies to ship their trucks instead of travelling the same route by road only. In the case of the fastest ships, their smaller cargo capacity results in noticeably poor environmental performances, leading to even negative saving rates compared with truck emissions for the same route. Keeping in mind only the scenario where ship A is compared with road transport as being the only marine option providing external costs savings, the bonus potentially offered by the administration to the truck company would be a maximum of 14.7 cents per kilometre not travelled by the truck. Nonetheless, some authors (e.g. García Menéndez, Martínez and Piñero 2003, and Pérez 2004) found that, as far as modal shift is concerned, the maritime share would grow in a higher proportion as result of an increase in road transport cost rather than a decrease in the price of freight. Crossed elasticity in the choice of maritime transport over road transport is about 1.075%; that is, the probability of selecting maritime transport increases by 1.075% for each 1% of road transport cost increase. An improvement of customer service or faster customs procedures in maritime transport results in an elasticity rate of about 0.641%. This means that a reduction in freight transport costs of approximately 1% would increase the probability of choosing sea transport by 0.641% only.

5 CONCLUSIONS

The intermodal option provides hardly any external cost savings for the five routes because the difference between road and sea distances is sometimes negligible. In addition, road legs in intermodal chains are too long, and increasing oil prices pose a threat to high speed crafts, which are heavily penalized for their high consumption rates, which lead to higher operational costs. Furthermore, there is concern about poor environmental performance. Conventional ships are the most environmentally friendly ones, the difference between fast conventional and high speed crafts being bigger than between conventional and fast conventional ships. This slight advantage of conventional ships would be eliminated if stricter regulations (Euro VI) for road transport were applied, particularly if no other measure is taken for sea transport. However, the better environmental performance of ships serving specific intermodal transport routes could justify the allocation of public grants as an economic incentive to convince users to choose maritime transport. An example is the environmental bonus offered by the Italian government in several routes to endorse trailers and trucks boarding ships instead of covering routes by road only. This action has also been taken by the Basque autonomous government in Spain.

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4.2
Applying graph theory terms to description of VTS

K. Jackowski
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The paper presents an example of applying graph theory notation to description of a VTS; it also contains some remarks on applicability of such notation for marine traffic systems

1 INTRODUCTION

Nowadays – as VTSes are growing in number and their area is still expanding – it may be advisable to take into account description of marine traffic systems in terms of graph theory, with the purpose of finding its advantages or disadvantages. A model of a VTS, assumed to illustrate an application of graph theory formalism, need not be very complex (though it is the formalism invented for depicting and analysing various traffic systems of great complexity).

2 EXAMPLE OF DESCRIPTION

Let system in consideration comprises two fairways leading to pilot station, two anchorages and one fairway from pilot station to port entrance. Its graph representation is shown in Fig. 1

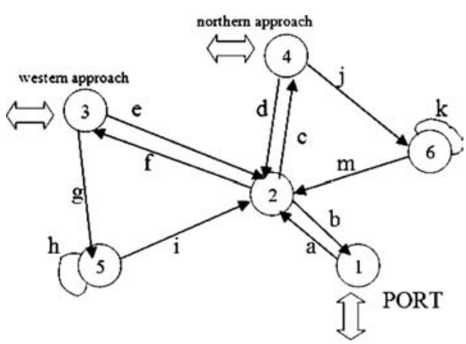

Figure 1. VTS graph:
vertex 1 – port entrance
vertex 2 – pilot station
vertex 3 – western reporting point
vertex 4 – northern reporting point
vertex 5 – western anchorage
vertex 6 – north-eastern anchorage
arcs (directed branches) a,b,c,d,e,f,g,i,j,m
– stand for traffic lanes
loops h,k – for denoting anchored vessels.

Graph arcs can also have a numerical notation, for instance: a → (1,2), b → (2,1), c → (2,4), d → (4,2), e → (3,2), f → (2,3), g → (3,5), i → (5,2), j → (4,6), m → (6,2).

Incidence matrix **J** of the graph and its binary matrix of adjacency **A** are as follows:

$$
J = \begin{bmatrix}
+1 & -1 & 0 & 0 & 0 & 0 \\
-1 & +1 & 0 & 0 & 0 & 0 \\
0 & -1 & 0 & +1 & 0 & 0 \\
0 & +1 & 0 & -1 & 0 & 0 \\
0 & -1 & +1 & 0 & 0 & 0 \\
0 & +1 & -1 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 & +1 & 0 \\
0 & 0 & 0 & 0 & 2 & 0 \\
0 & +1 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & -1 & 0 & +1 \\
0 & 0 & 0 & 0 & 0 & 2 \\
0 & +1 & 0 & 0 & 0 & -1
\end{bmatrix}
$$

(In incidence matrix: +1 denotes arc directed towards the vertex, 2 symbolizes the loop).

$$
A = \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 1 & 1 & 1 \\
0 & 1 & 0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 & 0 & 1 \\
0 & 1 & 1 & 0 & 1 & 0 \\
0 & 1 & 0 & 1 & 0 & 1
\end{bmatrix}
$$

The graph has no edges, which means that along each traffic lane vessels may proceed in one direction only.

With the allowance for the established direction of traffic flow, the adjacency matrix **A** transforms into matrix **B**:

$$B = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 \end{bmatrix}$$

At any moment a traffic in the system can generally be characterized by flow matrix **F** determining the number of vessels which have departed from a point (matrix $\mathbf{F}_O$ of outcoming traffic, with graph vertices as its sources) or vessels making for a point (matrix $\mathbf{F}_I$ of incoming traffic, vertices as outlets).

Let an example traffic distribution (for the system in consideration) be given by flow matrix **F** in one of the following forms:

$$F_O = \begin{bmatrix} 0 & 6 & 0 & 0 & 0 & 0 \\ 4 & 0 & 2 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 3 & 0 & 0 & 0 & (0) \\ 0 & 1 & 0 & 0 & (3) & 0 \\ 0 & 2 & 0 & 0 & 0 & (4) \end{bmatrix}$$

or

$$F_I = \begin{bmatrix} 0 & 4 & 0 & 0 & 0 & 0 \\ 6 & 0 & 1 & 3 & 1 & 2 \\ 0 & 2 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & (3) & 0 \\ 0 & 0 & 0 & (0) & 0 & (4) \end{bmatrix}$$

where numerals in brackets (3),(4) denote vessels awaiting at anchor and symbol (0) indicates that there is no traffic in the lane.

(It is easy to notice, that $\mathbf{F}_O^T = \mathbf{F}_I$, that is each matrix is transposition of the other.)

Instead of matrices $\mathbf{F}_O$, $\mathbf{F}_I$ (related to vertices) there can be used matrix $\mathbf{F}_B$ for all graph branches:

$$F_B = \left[\begin{array}{cccccc} -6 & +6 & 0 & 0 & 0 & 0 \\ +4 & -4 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & +1 & 0 & 0 \\ 0 & +3 & 0 & -3 & 0 & 0 \\ 0 & +1 & -1 & 0 & 0 & 0 \\ 0 & -2 & +2 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & +1 & 0 \\ 0 & 0 & 0 & 0 & (3) & 0 \\ 0 & +1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & (4) \\ 0 & +2 & 0 & 0 & 0 & -2 \end{array}\right] \begin{array}{l} a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \\ i \\ j \\ k \\ m \end{array}$$

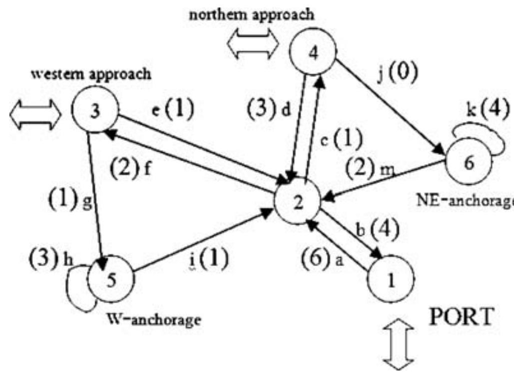

Figure 2. Graph of traffic.

where algebraic signs mark the direction of an arc (minus, if directed from a vertex, plus – if towards it); the numbers of vessels at anchor in brackets (as above).

The traffic network defined by matrices $\mathbf{F}_O$, $\mathbf{F}_I$ or $\mathbf{F}_B$ is illustrated in Fig. 2, (next page), where:
vertices – 1,2,3,4,5,6;
arcs (traffic lanes) – a,b,c,d,e,f,g,i,m;
(in brackets the number of ships underway);
arc (lane) – j (with no traffic);
loops – h & k (in brackets the number of vessels at anchor).

Matrices $\mathbf{F}_O$, $\mathbf{F}_I$ or $\mathbf{F}_B$ and its graph representation constitute a very general description, however. To give more detailed information, each arc of the graph (i.e. each traffic lane in the system) should have its ascribed vector of state which, at any given moment, characterizes the traffic flow in the lane. (And similarly, each vertex can be described by its state vector as well.)

For instance, state vectors describing port approach fairway at a chosen moment could be as follows:

a (lane 1,2):
$[0^H15^M, 0^H40^M, 0^H55^M, 1^H25^M, 1^H55^M, 2^H10^M]$,
b (lane 2,1):
$[0^H20^M, 0^H45^M, 1^H10^M, 2^H15^M]$, where vector **a** (1,2), for 6 vessels proceeding to pilot station, gives remaining time to go for each of them and vector **b** (2,1), for 4 vessels approaching port entrance – remaining time to enter the harbour.

Exemplary state vectors for anchorages,

h (5,5):
$[3^H15^M, 6^H30^M, 10^H00^M]$
and **k** (6,6):
$[0^H30^M, 2^H45^M, 8^H00^M, 12^H00^M]$,

define time to wait at anchor, for each vessel. (For vertices, which are junction nodes of the traffic system, the notion "state" may mean whether the node is accessible and passable, or not.)

Of course, the examples given are the simplest ones. The vectors of state, if necessary, may include many more particulars, such as next destination point or allotted berthing place, kind and amount of cargo, some ship's data, existing restrictions and constrains etc. (And for such "vertex", as p o r t, the state of the "point" may depend, in very complex and sophisticated way, on internal port traffic, cargo handling operations and other technical and economical factors.)

Vectors of state of every traffic lane and waiting area (**a**, **b**, **c**, **d**, **e**, **f**, **g**, **h**, **i**, **j**, **k**, **m**) together with state vectors of vertices ($\mathbf{v}_1, \mathbf{v}_2, \mathbf{v}_3, \ldots, \mathbf{v}_6$) and flow matrix **F** define the state of the whole system.

Transformation of state may be determined by two sets of functions:

$\{\mathbf{v}_x(t)\}$ for vertices and $\{\mathbf{w}_u(t)\}$ for arcs,

where t denotes time; (in considered example of traffic system, index x: 1,2,3,4,5,6 and u: a,b,c.d,e,f,g,h,i,j,k,m);
these functions also implicate transformation of flow matrix: $\mathbf{F}(t) = \mathbf{F}(\{\mathbf{v}_x(t)\}, \{\mathbf{w}_u(t)\})$.

In general, transformation functions are deterministic, but they may include statistical parameters and random variables as well, or be stochastically modified. It would be useful to reckon and apply such transformation operators **W**, **V**, **T**, that:

$$\mathbf{w}_u(t) = \mathbf{W}(t, t_o)\, \mathbf{w}_u(t_o),$$

$$\mathbf{v}_x(t) = \mathbf{V}(t, t_o)\, \mathbf{w}_u(t_o),$$

$$\mathbf{F}(t) = \mathbf{T}(t, t_o)\, \mathbf{F}(t_o) \text{ or } \mathbf{F}(t) = \mathbf{T}(t)\, \mathbf{B}$$

Finding affine forms

W, **V**, **T**,

however, is not an easy task, as usually the problem is non-linear, or the attempts to solve it may entail the necessity of inversion of a singular matrix.

3 FINAL REMARKS

Graph description of traffic systems is inseparably associated with matrix algebra formalism. A major practical difficulty with application of this description, as it seems now, is the problem of finding linear (matrix) operators for transformation of state of the depicted system. Searching for a solution may be done in the way of decomposing the transformation into a few stages, doing indispensable simplifications and finally introducing such variables and parameters (resulting from the intermediate stages of transformation), which – albeit somewhat artificial – make possible to express transformation of state by required matrix operators. It is clear, that such decomposition can not be excessive (too many stages of transformation may turn one complex problem into another) and also that undue simplifications may affect negatively the result of transformation.

All of these may hinder the application of graph description to marine traffic systems.

On the other hand, however, its expected advantages are obvious. Matrix notation is especially suitable for real-time automatic data processing and ensure obtaining requested information quickly and easily.

As to problems with creation of dynamic graph models of traffic systems, which may arise in case of very complex and extensive systems – they can be overcome gradually: by proceeding from simplest version of the description towards more sophisticated ones.

The existing possibilities of simulation experiments and examining the effects of theoretical investigations by simulator tests shall make it manageable.

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4.3 Simulation-based risk analysis of maritime transit traffic in the Strait of Istanbul

B. Ozbas & I. Or
Boğaziçi University, Istanbul, Turkey

O.S. Uluscu & T. Altıok
Rutgers, The State University of New Jersey, NJ, USA

ABSTRACT: In this manuscript, development and preliminary results of a simulation based risk modeling study for the Strait of Istanbul is presented. The goal of this research is to analyze the risks involved in the transit vessel traffic in the Strait of Istanbul. In the first step of the study, the transit vessel traffic system in the Strait of Istanbul has been investigated and a simulation model has been developed. The model gives due consideration to current traffic rules and regulations, transit vessel profiles and schedules, pilotage and tugboat services, local traffic, meteorological and geographical conditions.

Regarding risk assessment, two sets of factors are used to evaluate the risk of accident in the Strait: the probability of an accident and its potential consequences, as estimated and evaluated at various points along the Strait. Experience has shown that maritime accident occurrences can be very dissimilar from one another and therefore, probabilistic analysis of accidents should not be done independent of the factors affecting them. Thus, in this study, we have focused on the conditional probability of an accident, under a given setting of various accident causing factors. Unfortunately, historical accident data is by far insufficient for a proper statistical consideration of all possible settings of these factors. Therefore, subject-expert opinion is relied upon in estimating these conditional accident probabilities. Assessment of the consequences of a given accident (in terms of its effects on human life, traffic efficiency, property and environment) was also accomplished using a similar approach.

Finally, by integrating these assessments into the developed simulation model, the risks observed by each vessel at each risk slice are calculated in regard to the natural and man-made conditions surrounding. A scenario analysis is performed to evaluate the characteristics of the accident risk as the vessel moves along the Strait. This analysis allows us to investigate how various factors impact risk. These factors include vessel arrival rates, scheduling policies, pilotage service, overtaking and pursuit rules, and local traffic density. Policy indications are made based on the results of these scenarios.

1 INTRODUCTION

The Turkish Straits (the Straits of Istanbul and Canakkale), which have narrow and winding shapes that give them the semblance of a river, are one of the most strategically important waterway systems in the world. As the Black Sea's sole maritime link to the Mediterranean and the open seas beyond, they are a vital passageway not just for trade but for the projection of military and political power. Also, their hard to navigate geographical properties, meteorological conditions, dense and increasing transit/local traffic, vessel/cargo characteristics, and physical hindrances, such as cross continental bridges, energy transfer lines, make the Straits' traffic conditions quite complex and risky. Moreover, this narrow passage runs through the heart of Istanbul, home to over 12 million people and some of the world's most celebrated cultural and historical heritage.

Geographically, the Strait of Istanbul is one of the narrowest waterways in the world. It has length of 31 kilometers with an average depth of 45 meters (Ozturk, 1995). Its average width is 1.5 km, where this width decreases to 700 meters at its narrowest point (Tan & Otay, 1999). Additionally, frequent adverse meteorological conditions, such as dense fogs and high currents and winds, contribute to the complexity of navigation in the Strait.

There are also some non-natural factors making navigation through the Strait of Istanbul hazardous. One of them is the dense local traffic, such as intra-city passenger boats, fast ferries, fishing boats, pleasure boats, tugboats etc. (VTS User Guide, 2004). Another important non-natural factor that negatively effects navigation in the Strait is the frequency and cargo characteristics of transit vessels. Over 56,600 vessels (10,050 being dangerous material carriers) traveled through the Strait of Istanbul in 2007.

In order to control and mitigate maritime accident risks and improve the safety of navigation in the described dire environment, The Bureau of Turkish Strait's Maritime Traffic Services (BMTS) has set up

Figure 1. The Strait of Istanbul.

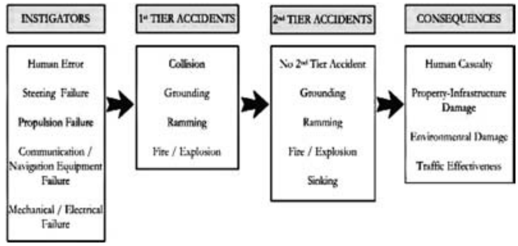

Figure 2. The framework of the risk model.

a sophisticated Vessel Traffic Control & Monitoring System (VTS), (covering not only the Strait, but also 20 miles into the Black Sea and the Sea of Marmara) and has established and effected a set of stringent Maritime Traffic Rules and Regulations (R&R). The vessels arriving at the northern and southern entrances of the Strait of Istanbul enter and then navigate through the Strait according to the directions of the BMTS, which are based on the VTS inputs and the R&R (VTS User Guide, 2004).

The objective of this study is to analyze the risks involved in the transit vessel traffic in the Strait of Istanbul. In order to achieve this, a detailed mathematical risk analysis model is developed to be used in a risk mitigation process (Uluscu et al., 2008). Firstly, in order to study and better understand the system, a functional simulation model of the transit vessel traffic in the Strait of Istanbul is built. In this simulation, which is based on the mentioned R&R, in addition to the geographical/meteorological conditions, transit and local vessel traffic in the Strait, the current vessel scheduling practices are also modeled using a specially designed scheduling algorithm. This scheduling algorithm, which is developed through discussions with the BMTS authorities, primarily mimics their decisions on sequencing vessel entrances, as well as northbound and southbound traffic flow time windows (Uluscu et al., 2009). Finally, by integrating, expert opinion and historic data based risk assessments into the developed simulation model, the risks generated by each vessel, are calculated in regard to the natural and man-made conditions surrounding it (such as, vessel characteristics, pilot/tugboat deployment, proximity of other vessels, current & visibility conditions, location in the Strait etc.), as the vessel moves along the Strait. Preliminary results obtained in the application of this procedure are presented and discussed in later sections.

2 MODELING RISK

The primary objective of this study is to develop a realistic model to assess and investigate maritime risk imposed by the transit traffic in the Istanbul Strait; furthermore, it is expected that such a model and an accompanying scenario analysis will suggest and support strategies and operational policies that will mitigate the risk of maritime accidents that will endanger the environment, the inhabitants of Istanbul and impact the economy, while maintaining an acceptable level of vessel throughput.

Regarding the modeling of risk, first events that may trigger an accident are identified and defined as instigators (for example, there can be a mechanical failure in the vessel or the captain can make a judgmental error, during the transit of the vessel through the Strait of Istanbul). Through the examination of the historical accident data and discussions with local maritime experts, the occurrences of the following incidents have been identified as possible instigators of maritime accidents in the Strait: human error, rudder failure, propulsion failure, communication and/or navigation equipment failure, and other mechanical and/or electrical failure. Clearly, the occurrence of an instigator depends on the situation, which may be represented by a vector of situational attributes. Given the occurrence of an instigator, typical accidents that may occur in the Strait have been considered and classified as, collision, grounding, ramming, sinking and fire and/or explosion. It is also possible to have accidents may occurring in chain, so that a prior (1st tier) accident may cause later (2nd tier) one. 1st tier accident types include collision, grounding, ramming and fire and/or explosion, while the 2nd tier accident types include grounding, ramming, fire and/or explosion, and sinking. Potential consequences of the 1st and 2nd tier accidents include human casualty, property and/or infrastructure damage, environmental damage and loss of traffic effectiveness and throughput. This framework is presented in Figure 2. Defining situations (factors and their states) that affect the likelihood and/or impact level of instigators and accidents is critical for the intended risk analysis. Such factors as called Situational Attributes, and are divided into two groups: attributes influencing accident occurrence (vessel class, vessel reliability, pilot request, tugboat request, visibility, current, local traffic density, vessel proximity, zone and time of the day) and attributes influencing consequences (vessel cargo, length, zone). These two groups of situational attributes (are displayed in Figure 3 and 4.

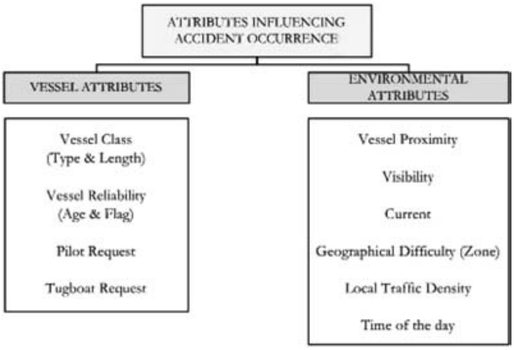

Figure 3. Situational attributes influencing accident occurrence.

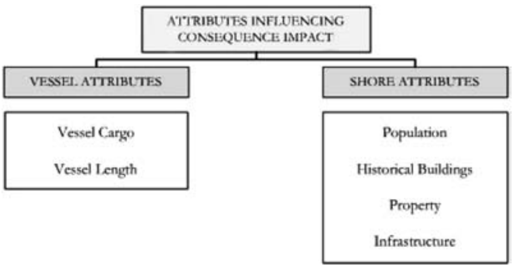

Figure 4. Situational attributes influencing the consequences.

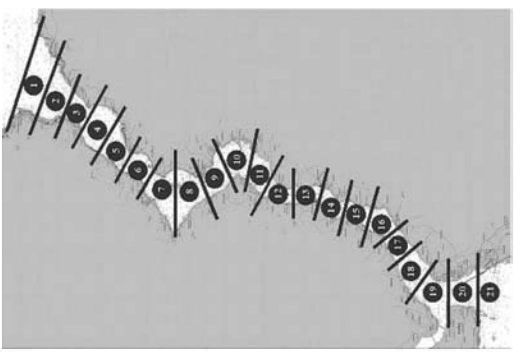

Figure 5. Risk slices at the Strait of Istanbul.

Given the above described framework, the following questions need to be answered in order to quantify risks:

- How often do the critical situations occur?
- For a particular situation, how often do instigators occur?
- If an instigator occurs, how likely is an accident?
- If an accident occurs, what would the damage to human life, property, environment and infrastructure be?

In this study, answers are provided to these questions (and risk quantification accomplished) based on historical data, expert judgment elicitation and simulation model generated output regarding the state of the situational attributes. The 21 slice division of the Istanbul Strait, depicted in Figure 5 (each slice being 8 cables long) assumed in the simulation model, is also pursued for risk analysis purposes. The risk at a slice is calculated based on the snapshot of the traffic in that slice every time a vessel enters it.

In order to calculate risk, the product of two sets of factors is sought for associated with each transit: the probability of an accident and the potential consequences of this accident, during that particular transit. Since two groups of accidents are considered (1st and 2nd tier accidents), the expected slice risk can be calculated accordingly.

$$R = \sum_{\substack{\text{Vessels}\\\text{navigating}}} \sum_{\substack{\text{1st tier}\\\text{accident types}}} \sum_{\substack{\text{2nd tier}\\\text{accident types}}} \left(\sum_{\substack{\text{Consequence}\\\text{types}}} E[\text{Consequence type}|\text{1st tier accident type}] \times \Pr(\text{1st tier accident type}) + \sum_{\substack{\text{Consequence}\\\text{types}}} E[\text{Consequence type}|\text{2nd tier accident type}] \times \Pr(\text{2nd tier accident type}) \right) \quad (1)$$

Pr(*1st tier accident type*) is obtained using conditional probabilities of all possible accidents given situations (e.g. visibility) and instigators (e.g. human error); conditional probabilities of instigators given situations; and finally probabilities of situations.

Pr(*2nd tier accident type*) is obtained using conditional probabilities of all possible 2nd tier accidents given 1st tier accidents and probabilities of 1st tier accident occurrences.

E[*Consequence type*|*Accident type*] is obtained using the consequence impact levels, conditional probabilities of all possible consequences given accidents and situations and finally probability of situation.

To be able to calculate the expected risk, *R*, as shown above, most of the accident and consequence probabilities (conditioned on the occurrence of instigators and/or state of situational attributes) are obtained via elicitation of expert judgments; other probabilities (e.g. instigator and 2nd tier accidents probabilities) are obtained from the historical data. The specific states of the many situational attributes are obtained from the simulation model (as the vessels generated in the model move through the Strait, in the environment also generated by the model).

Experience has shown that maritime accidents can be quite different from one another in terms of factors causing them. As introduced above, various conditional probabilities of accidents are sought after in this study. Unfortunately, historical data has been insufficient for a proper statistical analysis of these probabilities. Therefore, expert opinion has been relied upon in their estimation. Expert opinion on accident probabilities is obtained through an elicitation process using questionnaires focusing on pairwise, uni-dimensional (one at a time) comparisons of factor (situational attribute) settings (while keeping the remaining factors at pre-determined fixed levels).

Conditional probabilities of accident consequences (in terms of low, medium or high effects on human life,

Table 1. Consequence impact levels.

Impact level	Value
Low	Uniform(0–1,000)
Medium	Uniform(4,000–6,000)
High	Uniform(8,000–10,000)

traffic efficiency, property, infrastructure and environment) are also determined through a similar elicitation process. On the other hand, quantification of these qualitatively defined impact levels is accomplished through parameterization. One such set of parameters assumed (for different levels of consequence impacts) is presented in Table 1. These values do not represent the actual consequence of an accident in specific units (e.g. dollars or number of casualties). Instead, index values representing the experts' perceptions of low, medium and high consequences are utilized. As a result, the calculated risk values are meaningful when compared to each other in a given context.

Finally, these assessments are integrated into the simulation model such that the risks observed by each vessel, at each slice are calculated and compiled considering all the natural and man-made conditions surrounding the slice and the vessel (such as, vessel characteristics, pilot/tugboat deployment, proximity of other vessels, current and visibility conditions, location in the Strait etc.), as the vessels moved along the Strait.

3 OBSERVATIONS

Experimentation with the aggregate simulation/risk model described above has been accomplished through a scenario analysis. In this regard, first the parameter values reflecting the current situation in the Strait, based on year 2005–2006 data (such as, vessel arrival rates, overtake and pursuit distances, vessel entrance schedules, local traffic density etc.) is compiled into a "base scenario". The risk profiles of this "base scenario" (in terms of average slice risks and average maximum risks), obtained using 25 replications (simulation runs) – each of one year length, are displayed in Figure 6. The average slice risk profile exhibits a steady behavior from the north entrance all the way down to the Bogazici Bridge, where the effects of the high local traffic activity in these highly populated and busy regions of the Strait start becoming significant. Interaction of the transit and local traffic patterns generates a large spike in the average risk in Slice 19 (this is the Strait region corresponding to downtown Istanbul and including the main harbor area) and somewhat tapers off around the south entrance. The average maximum risk profile also exhibits a similar behavior but featuring 200 to 850 fold increases from average risks levels observed at various points along the Strait. This remarkable observation indicates how risky the maritime traffic in the Strait of Istanbul can get at

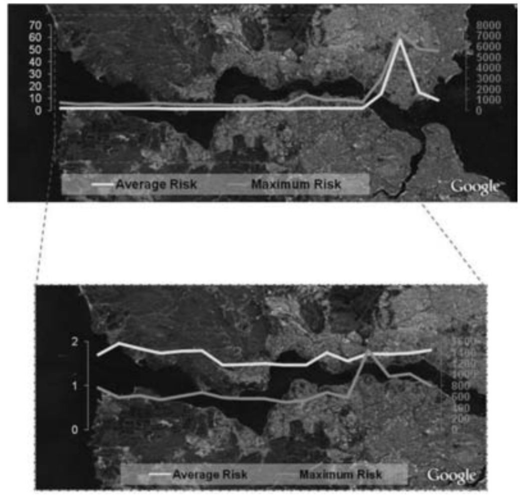

Figure 6. Current risk profiles of the Strait of Istanbul.

specific instances. That is, depending on random realizations of accident causing factors, ordinary and safe appearance of the Strait maritime activity could swiftly change into a very risky environment. For example, a rare realization observed in Slice 1 (corresponding to risk value 12210) involved an excessive level of fog during nighttime and two D-class vessels that just entered the slice before the Strait is closed. Another rare realization, observed in Slice 19 (corresponding to risk value 10710), involved an A-vessel that was about to leave the Strait just after the night schedule started, a D-vessel and an E-vessel along with 10 local vessels. Such potentially highly dangerous situations may be rare, but a rare disaster is a disaster too many. So, high risks indicated by the maximum risks should be taken seriously.

Next, a series of scenarios has been constructed and compared against the base scenario (through the aggregate model), in order to investigate the characteristics of accident risks in the Strait under different settings and conditions. In Scenarios 1 and 2, arrival rate of hazardous cargo vessels are increased and decreased. In Scenarios 3–9, vessels are scheduled with lesser and greater pursuit distances. In Scenario 10, pilot captain service is turned off. Scenario 11 represents the case where overtaking is not allowed within the Strait. Finally, local traffic density in the Strait is decreased by 50% in Scenario 12. An average maximum slice risk profile is given in Figure 7. This analysis has provided us with the ability to observe and predict how changes in various policies and practices impact the risk profile of the Strait. The results and important observations accomplished are summarized below.

3.1 *Observation 1*

The accident risks in the Strait and the average vessel waiting times exhibit a tight and sensitive balance.

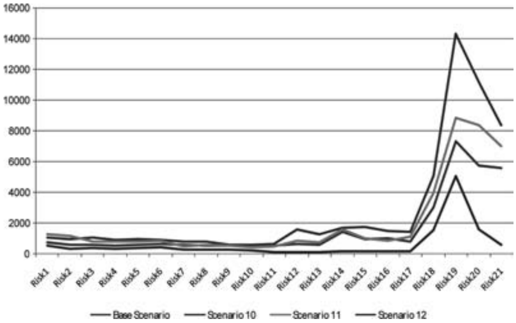

Figure 7. Maximum slice risk in Scenarios 10, 11, and 12 compared to the base scenario.

For instance, a small increase in arrival rates may result in rather high waiting times at the entrances (an increase of 60% for some vessel classes). Furthermore, scheduling changes made to reduce vessel waiting times increase risks in the Strait substantially. Conversely, one has to be very careful in revising the scheduling mechanism for the purpose of risk mitigation, since the waiting times are highly sensitive to entrance rules. The benefits obtained in risks may not justify the resulting waiting times. In the future, scheduling changes may be justified, if significant reductions occur in the transit vessel traffic, perhaps due to alternative oil transport modes such as pipelines and other routes. Thus, scheduling decisions to balance out delays vs. risks should be made based on extensive experimentation with the model developed in this study.

3.2 *Observation 2*

The model indicates that pilots are of utmost importance for safe passage, and lack of sufficient pilotage service significantly increases the risks in the Strait. Currently, vessels longer than 250 m. are mandated to take a pilot, and it is voluntary for the rest. As a result of our experimentation, we have recommended mandatory pilotage for vessels longer than 150 m. This will reduce the average risk by 7%, the average of maximum risk by 11% in Slice 19 and the observed maximum risk is 11114 observed in Slice 3 (almost 7,000-fold of its average). Had pilotage been obligatory for vessels longer than 100 m., this would reduce the average risks by 46% and the average of maximum risks by 33% at Slice 19.

3.3 *Observation 3*

Even though current regulations discourage overtaking anywhere in the Strait, results indicate that overtaking a vessel is less riskier as opposed to requiring a pursuing faster vessel to slow down behind a slower vessel, where the average slice risk and the average of maximum risk are increased by 28% and 21% in Slice 19, respectively. In the latter case, the maximum observed risk is 23030 (almost 13,000-fold of its average) observed in Slice 1. Therefore, in the regions where the geography of the Strait tolerates it, overtaking seems to be a safe practice (as also suggested by expert opinion).

3.4 *Observation 4*

The most significant contributor to risk appears to be the juxtaposition of the transit vessel traffic and the local traffic. When the local traffic density in the Strait is decreased by 50% during daytime, it results an 83% decrease in the average risk and 31% decrease in the average maximum risk of Slice 19. Accordingly, for potential risk mitigation, the scheduling procedure maybe revised to enable a more effective night-time traffic at which time there is almost no local traffic. However, this issue requires further research regarding the kind of modifications that can be done to the scheduling practice to accommodate a larger volume of night-time traffic, hopefully without increasing overall vessel delays or other risks.

4 CONCLUSION

The nature of the global economy and international politics dictates that the maritime transit traffic in the Strait of Istanbul cannot be greatly reduced nor eliminated. Nonetheless, the economic/political realities and environmental awareness and risk management need not to be mutually exclusive goals in the Strait. The risks regarding the transit traffic can be mitigated by operational policies and rules that adequately regulate and guide the transit traffic, while maintaining the freedom of passage. Until then, the environment, the priceless historical/cultural heritage and the health and safety of the city's residents will be at jeopardy.

In this paper, a comprehensive analysis of safety risks of the maritime transit traffic in the Strait of Istanbul is discussed. This analysis is carried out through the development and deployment of a detailed hybrid mathematical/simulation model. This model, which is based on extensive objective and subjective data from a large number of sources, provides a realistic and valid representation of the maritime traffic operations and their impacts at the Strait of Istanbul with many interesting results.

Our primary conclusions are in the direction of maintaining the current scheduling/sequencing procedures to let transit vessels enter the Strait, while enforcing pilotage service on a larger scale and seeking more efficient and heavier deployment of night-time conditions, where the local traffic activity is almost negligible.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

4.4 The Marine Electronic Highway project in Straits of Malacca and Singapore: Observation on the present development

M. Hafizi Said & A.H Saharuddin
Universiti Malaysia Terengganu, Malaysia

ABSTRACT: Implementation of the Marine Electronic Highway (MEH) project in Straits of Malacca and Singapore will complement the efforts taken by Malaysia, Indonesia and Singapore as littoral states in enhancing safety of navigation and the prevention and control of marine pollution in the Straits. The Project Steering Committee meetings of the MEH indicate that, the progress in the implementation of its activities is in the midst of many challenging conditions. The efforts is a testament that the littoral states are working together to ensure the implementation of this project is running smoothly since the donor agencies, user States and the maritime industry have great expectations on its success. The MEH project consists of four important components such as Hydrographic Survey and Electronic Navigational Charts (ENCs) production, Environment Marine Information Overlays, Baseline Survey and Information Technology Structure. This paper will address the current status of the implementation of the four key components highlighting the development of ENCs as a vital tool to sustain the safety of navigation along the straits. The discussion in this paper is based on some preliminary survey findings and from reports of the Project Steering Committee meetings.

1 INTRODUCTION

The Marine Electronic Highway (MEH) in Straits of Malacca and Singapore is an innovative marine information and infrastructure system that integrates environmental management and protection systems and maritime safety technologies for enhanced maritime services, higher navigational safety standards, integrated marine environment protection and sustainable development of coastal and marine resources. The key of the MEH is precision navigation and will utilize a network of Electronic Navigational Charts (ENCs) in conjunction with Electronic Chart Display and Information System (ECDIS), Differential Global Positioning System (DGPS), Internet Broadband and other maritime technologies (K.Sekimizu, 2003).

2 PROJECT BACKGROUND AND STATUS

2.1 *Background and objectives*

Straits of Malacca and Singapore are a historically important sea route for international and local maritime trade as well as being one of the world's busiest sea lanes, a unique and rich tropical estuarine environment, a major shipping route for petroleum oil tankers, and one of the highly vulnerable waterways used for international navigation with a high incidence of marine casualties and oil spills. Geographically, the Straits extend more than 900 km between Peninsula of Malaysia, Indonesia and Singapore. The narrowest point is the Philips Channel which is 1.3 nautical miles wide and 23 meters depth. The Straits have many more chokepoints particularly at One Fathom Bank and Batu Berhenti. These chokepoints are critically important to the oil and natural gas trade. Consequently, the large ships of 200,000 ton and above or VLCC have to rush for the channel during high tide period (Hiroshi Sekine, 2006).

Since 1980s, several initiatives for the Straits were undertaken, which covered various aspects of maritime activities, safety of navigation and marine environment protection. The fruition of those initiatives is mainly through the Co-operative Mechanism on Safety of Navigation and Environment Protection. Project. Then in late 1990s, the concept of MEH has been introduced. This new concept having concerned that the high risk of ship accidents along the congested water in the Straits.

Safety and security of navigation and environmental protection are the main concern. Therefore the MEH project aims to provide a practical demonstration in the Straits of the potential for digital information networks that can provide environmental and related information in real time to both mariners transiting the Straits as well as other agencies and interested parties. The Project includes obtaining high-quality hydrographic surveys of some of the most limiting depth areas in the Straits, the development of ECDIS compatible with Marine Information Overlays (MIOs), the establishment of a unified data centre to provide real time information and updates, and the establishment of a number of environmental monitoring stations including tide gauges and current meters.

The MEH was designed in two main stages namely demonstration and full scale. Demonstration project will cover parts of the Straits, mainly the area of the Traffic Separation Scheme. The second stage or full-scale project, which will follow after this initiative, will cover the whole Straits including the coastal waters of the Littoral States. The demonstration stage aims to show how environmental data related to the Straits, such as the nature and extent of environmentally sensitive areas can be accessed by the relevant authorities using a common database; how new or revised routing instructions or prohibited areas can be broadcast to ships taking part in the demonstration; and how Mariners can receive other environmental information such as real-time tidal observations, tidal streams, sea conditions and wind, in ECDIS via MIOs.

2.2 *MEH time line*

Table 1. The MEH Progress (Hartmut Hesse, 2008).

Important event	Date
Established Project Management office at Batam, Indonesia	May, 2007
1st Project Steering Committee Meeting – Batam, Indonesia	29–31 May 2007
Hydrographic survey bidding	October 2007
Bid evaluation report	January 2008
1st Technical Committee on Survey and ENCs meeting at Penang, Malaysia.	14–15 April 2008
2nd Project Steering Committee Meeting – Kuala Lumpur, Malaysia	3–5 June 2008
Full demonstration phases	Expected Mid of 2009

3 MEH KEY COMPONENTS

During the 2nd Project Steering Committee Meeting at Kuala Lumpur, the member considered four key components, namely the hydrographic survey, ENCs production, the Environment Marine Information Overlays (E-MIO) and the Information technology structure and data centre. The current statuses of these components are presented in the Table 2.

Outcome of the 1st Technical Committee Meeting held in Penang, Malaysia from 14–15 April 2008, the members had agreed that to reduce the scope of the survey to the prioritized areas as shown in Table 3. Having considered Area 1 of the Traffic Separation Scheme (TSS) as the most important of the 8 prioritized areas, the Meeting agreed that Area 1 met the holistic objective of the MEH project and therefore should be surveyed. This area is from One Fathom Bank to Tanjung Piai with an area of 621.28 km^2 or 14.38% of the prioritized areas as its first priority for survey.

Table 2. The current status of the MEH main components.

MEH main component	Current status	Remarks
Hydrographic survey and Electronic Navigational Charts (ENCs) production.	Hydrographic survey activity has been in the pipeline for over a year, including the tendering aspect, which has rejected due to insufficiency funds.	Reduction of scope of service (SOS) areas based on the eight (8) prioritized areas (refer to Table 3), beginning with Area 1. The additional areas will be considered options and may be surveyed subject to availability of funds. Ongoing negotiations with contractor.
Environment Marine Information Overlays. (E-MIO)	The Terms of References (TOR) for the E-MIO consultancy had agreed during 2nd PSC Meeting, June 2008 in Kuala Lumpur	The dynamic E-MIO data within the Straits agreed as bellow: 1 – Dynamic tide data. 2 – Real time notification of new restricted areas and routes. 3 – Real time environmental monitoring (such as wind, current and temperature.
Information Technology structure and database centre.	The fundamental principle of MEH Data System had been presented by IT consultant during TC-SIF meeting in September 2007 in Singapore.	The MEH Data system was based on Data format (open format using xml format file), Security of data (SSL protocol), Reliability (redundancy of all servers), Scalability and Sustainability.

Table 3. The Estimate Cost for 8 Prioritized Areas (Report of 2nd Project Steering Committee Meeting – Kuala Lumpur, Malaysia, 2008).

Survey area	No# of ship wrecks	KM^2	Estimated cost(bid)/ USD	Estimated days(ops)
Area 1	5	621.28	2,754,719	44.32
Area 2	2	140.15	584,548	14.67
Area 3	3	127.83	712,155	19.93
Area 4	0	10.65	163,966	2.65
Area 5	5	85.59	241,569	5.79
Area 6	2	33.61	173,315	3.02
Area 7	0	47.23	824,155	25.09
Area 8	2	279.91	824,155	25.09
Total	19	1,346.2	6,278,582	140.56

4 ENC AND E-NAVIGATION

4.1 *ENC production*

Electronic Chart Display and Information Systems (ECDIS) embraced the entire navigation system and have made it possible to concurrently address maritime safety and environmental protection management both at sea and ashore. However, in order to produce precise of charts, data and information needs to be made available. The mandatory carriage of ECDIS seem to be enforced, with reports from IMO's NAV54 subcommittee meeting confirmed that members have reached a consensus in favour of making the technology a required fit for ocean going vessels especially in highly traffic and congested water like Straits of Malacca and Singapore (Digital Ship, 2008). In view of that, the development of ENC and the require infrastructure have to be expedited.

According to the report from Singapore representatives during 2nd Project Steering Committee Meeting in Kuala Lumpur (2008), the latest edition of Singapore ENC consists of 14 cells and is produced in accordance with the IHO S-57 Edition 3.1 specifications. The Singapore ENC covers Singapore Waters and its approaches. It contains chart information necessary for safe navigation and supplementary information in addition to those in the paper charts. Monthly incremental of Singapore ENC updates are available over the Internet as well as through appointed ENC distributors.

4.2 *e-Navigation strategy*

Precision navigation shall be the backbone of the MEH upon which all the technological platforms would be integrated commencing with the ENCs-ECDIS. Precision navigation consists of onshore, sea based and ship-based facilities from which information and data flow into the network. Such facilities include transponders such as an Automatic Identification System (AIS) and onboard access to the Internet or broadband (K.Sekimizu, 2004). With AIS, real time information can be automatically provided to or received from appropriately equipped shore facilities or other ships. With enhanced AIS, hydrographical and oceanographic data including weather conditions can be transmitted or received, thereby facilitating ship movement, particularly in restricted or congested waterways as well as during inclement conditions (Digital Ship, 2008). Currently, AIS is mainly for basic ship information exchange.

In addition to acquiring, managing and achieving data in digital form, it is now apparent that common protocols necessary for optimum data transfer and sharing. Hence, the Littoral States's VTS and the MEH Data Center in Batam (Indonesia) need to use identical database software as a database engine to achieve the desires functionality. Currently, Singapore and Malaysia VTS use ORACLE 10 g. However, Indonesia has not yet built its VTS and could easily use the same platform.

However, future developments may include other relevant information such as weather data. AIS or similar facility, information flow could be real time, forecast, archived data, and monitoring/time lag data. The presence of a network of meteorological centers such as the South East Asian Centre for Atmospheric and Marine Prediction (SEACAMP) could provide higher resolution local weather conditions or forecasts that could be transmitted through the AIS allowing mariners to evaluate the weather conditions along their route. All of these strategies and technologies will be designed in order to achieve the aim of MEH as stated below:

– Facilitate vessel traffic monitoring and management,
– Facilitate communication and data exchange,
– Improve efficiency of transport and logistics,
– Effective operation of contingency, response and SAR,
– Provide human-machine interface, and
– Manage user workload and support decision making.

5 DISCUSSION AND CONCLUSION

5.1 *Towards a successful end product*

Based on the current status of the MEH project it is obviously indicated that the progress in the implementation of its activities is in the midst of many challenging conditions. According to Sally Burningham (2008) from World Bank in Jakarta, the MEH project has been under implementation with fund available since June 2006 but very little of the funds had been disbursed. Despite of this, the project actually needs more fund and strategies in order to accomplish. Thus, some of necessary steps to ensure success and expedite the MEH project shall include:

– Ensuring financial sustainability.
  Financial sustainability will only be achieved through an overall commitment of the governments of the respected countries, the oil and gas major transporters, fishing and shipping interests. Therefore, the US $8.68 million which provided by the Global Environmental Facility (GEF) is not sufficient enough due to certain escalations in cost in some elements of the Project (Ahmad, 2008). In addition, without extra fund from other parties or sponsors the MEH Projects encountering difficulties in adhering to the original scope and plan.
  Based on the suggestion made by Sasakawa (2007), he issues an invitation to the Straits user to agree to a voluntary payment of US 1 cent per ton for every vessel that transit through the Straits. Since annually more than 4 billion tons of cargo that passes through the Straits, these would raise 40 million dollar a year. This amount would more than enough to eliminate the excessive burden by the Littoral states (B.A Hamzah, 2008).
– Cooperative mechanism between littoral states and other straits user.
  In November 2004, the IMO Council at its 93rd meeting considered that the Straits of Malacca and Singapore as specific and vital shipping lane. Following that decision, in September 2006, three

littoral states (Malaysia, Indonesia and Singapore) together with Japan and other industry representatives such as INTERTANKO and ICS had developed the Cooperative Mechanism for maintaining safety of navigation and environmental protection of the Straits.

Subsequently, the industry and other Straits user are encouraged to participate in the Cooperative Mechanisms by making voluntary contributions to the Aids of Navigation Fund or either participating in the Cooperation Forum (R.Beckman, 2008). As major beneficiaries of safe and secure passage through the Straits, fairness and justice dictate that industry and other users should participate in the Cooperative Mechanisms.

– Involving public, private sector and academics stakeholders.

Reference in Article 43 of UNCLOS to user States does not preclude participation by industry or other private sectors. This Article avoids the legal problems that would arise if the Littoral States established mandatory tolls or charges. However, the private sector does not need to justify burden sharing and to undertake Corporate Social Responsibility (CSR) just because the Article 43 omits mention of the private sector. This is because cooperation in promoting common good is requiring under international law. Thus, the CSR role of the private sector especially for oil major companies and shipping interest should go beyond monetary contribution. The concept of CSR dictates that the private sector should recognised the shared responsibility to ensure safe and secure passage through vital international shipping lanes.

Beside that, scholars, academia, researchers and scientist from universities and institutions are encouraged to share idea, research finding and consultation on issues of common interest in the Straits. In recognizing the role they could play, the Littoral States and the MEH Project Steering Committee (PSC) should facilitate the concrete and practical cooperation methods. In this respect, the cooperation forum will be useful platform for the Littoral states and PSC to gather feedback. In addition, some fund should be allocated for research grant in order to make fruition of information through research finding.

5.2 *Conclusion*

The establishment of MEH Project is significantly important to the maritime industry. The efforts through Cooperative Mechanism and actively participated in PSC meeting are the testament that the littoral states and other stakeholder are working together to ensure the implementation of this project is running smoothly since the donor agencies, user States and the maritime industry have great expectations on its accomplishment.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

4.5
Availability of traffic control system based on servicing model

J. Mikulski
Silesian University of Technology, Katowice, Poland

ABSTRACT: Traffic control is a component of transport system, on which safety and efficiency of means of transport movements substantially depend. It is not possible to achieve and maintain appropriate availability of traffic control system unless issues of appropriate maintenance servicing of traffic control equipment have been resolved. This will require applying a specific servicing policy, worked out on the basis of such system availability model. The servicing of a technical object is understood as any treatment, which results in restoring the object's state of availability. Servicing may consist in a repair of equipment or in its inspection. Classification of servicing optimisation models, in respect of using appropriate mathematical methods, such as Markov models, is presented.

The main goal of transport consists of movements of various means of transport, carrying people and cargo. This process shall be carried out maintaining a high level of safety. To this end movements of means of transport are based on ordered principles of traffic organisation, which from the point of view of technical functionality are fulfilled by systems of vehicles movements' control, so-called traffic control systems. These systems enable execution, through equipment localised in various places of the transport network, of appropriate control algorithms.

All components and systems of transport traffic control are required to show operation certainty. The operation certainty is understood as a probability of defect non-occurrence. A defect consist in – at two-state classification – a transition of a piece of equipment (in defined operating conditions and at defined time) from the state of availability (fitness) to non-availability.

Transport traffic control systems work in diversified, frequently most critical, operating conditions. The experience from such equipment operation confirms the dependence of proper systems' functioning on reliability of their components.

In transport traffic control equipment defects may cause only traffic disturbances (e.g. delays), but also occurrence of dangerous situations.

Traffic control system is a set of pieces of equipment, which change their states between the state of availability (i.e. the state of fitness to execute a task or function in the system) and states of non-availability at discrete moments in time, i.e. they are dynamic states. The set of such systems' states is a discrete set. Transitions between the following states are stochastic in nature and occur at random, in accordance with certain probability distribution.

The operation of traffic control systems to a large extent shall focus on achieving appropriate availability of traffic control equipment and on maintaining it through a required period. This results in a need to resolve problems of appropriate maintenance service of traffic control equipment (repairs and inspections).

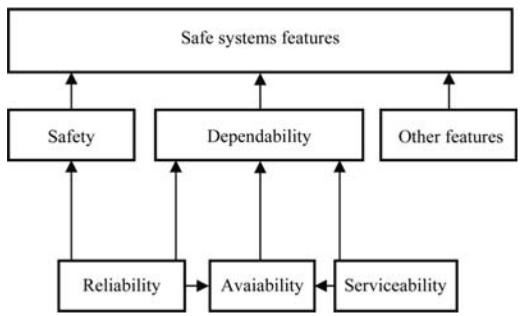

Figure 1. Links between features of safe systems.

Most important features of safe systems include: safety, availability, reliability, repairability.

Mutual links between main features of safe systems are presented in Figure 1.

The servicing of a technical object (equipment) – Figure 2 – is understood as any treatment, which results in restoring the object's state of availability (operational). Servicing may consist in a repair of equipment or in its inspection, replacement of the entire equipment with a new one or in replacement of damaged components with new ones. Parameters characterising the equipment at servicing must ensure that it is operational, although they may differ from a new object (in particular this refers to defects intensity).

An inspection, maintenance and condition control are comprised (apart from a repair) by so-called technical service of equipment, which is opposite to its use.

To prevent adverse effects of unpredicted defects (failures), equipment which is still in the state of availability (operational) is subject to servicing. Such

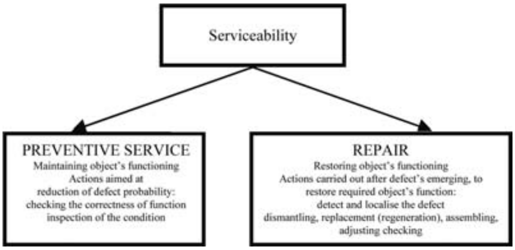

Figure 2. Servicing of a technical object.

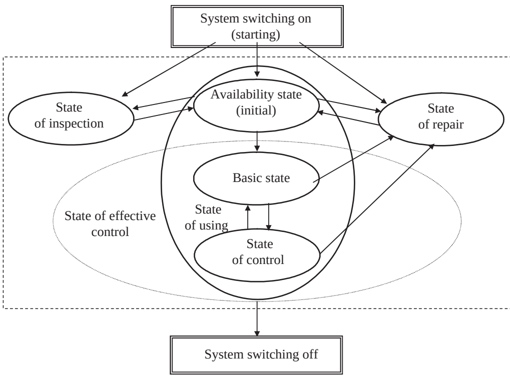

Figure 3. States of the transport traffic control system.

servicing is named preventive and distinguished from emergency servicing.

Properties of any system (in the case considered, of a transport traffic control system) indicate that such system, from the point of view of its servicing, may be presented (on certain level of generality) as a set of states of using, repair and inspection (Fig. 3). When analysing this diagram, the state of availability (initial) and the state of effective control (system transition between the basic state and the control state under influence of introduction of control command and after execution of the control task) may be distinguished within the state of using. But in servicing it is most important to distinguish the state of repair and inspection.

Classification of servicing optimisation models, both in respect of individual devices and systems, also because of using appropriate mathematical methods, such as inter alia linear and non-linear programming, dynamic programming, but first of all Markov models.

Game theory and stochastic processes theory, mainly of Markov processes, are used to model the process of technical objects operation (Koźniewska & Włodarczyk 1978). Mass servicing theory (referred to also as queuing theory) is strongly related to technology and its development resulted from practical demands.

In general form each queuing system may be presented using a block diagram (Fig. 4).

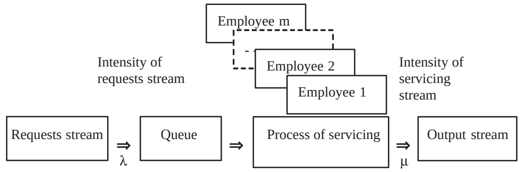

Figure 4. Block diagram of a queuing system.

A queuing system may be described using three basic characteristics:

– Stream of requests – this is a statistical description of process of requests arriving at the system,
– Process of servicing – defines the process of requests servicing performance,
– Queue regulation (discipline) – defines the method of selecting the next request to be serviced, if there is a queue in the system.

The case when these variables are subject to exponential distribution is of great practical importance.

The stream of requests is a statistical description of the process of requests arrival at the servicing system. It is usually described using distribution functions for intervals between consecutive requests. If this stream does not show variability, these intervals are constant and the stream itself is of deterministic nature. But if requests are arriving at the system at random, then these intervals are a random variable and then the function of their distribution should be defined (Filipowicz 1997).

The following denotations are used:

$\bar{t}_1$ – average length of interval between two adjacent requests,
λ – average intensity of requests stream (requests intensity).

The relation between these values has the following form

$$\lambda = \frac{1}{t_1}$$

Variable $\bar{t}_1$ stands for an important value in the reliability technique – it is so-called average time between failures. It is a measure of equipment reliability.

In practice it happens very often that the time of servicing is not constant and is subject to stochastic fluctuations. In such a case it must be described using appropriate distribution function. The time of servicing is an important value characterising the system of servicing. When considering the time of servicing as a random variable, its distribution function may be determined.

The following denotations are used:

$\bar{t}_2$ – average time of request servicing,
μ – average intensity of request servicing.

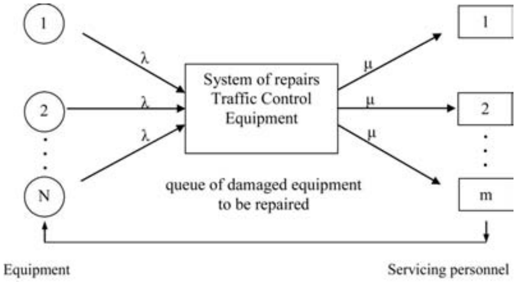

Figure 5. Visual diagram of transport traffic control equipment servicing.

The relation between these values has the following form

$$\mu = \frac{1}{t_2}$$

In the reliability technique the average time of request servicing may mean, apart from repairs, also servicing of inspections, and then inspections intensity is an inverse of average time between inspections.

A repair service of transport traffic control equipment (group of m service employees carrying out repairs of N pieces of equipment) is a typical queuing system. Each piece of equipment is a source of requests of intensity λ, while intensity of each employee servicing is equal μ. Overall requests intensity depends strictly on the number of damaged equipment, i.e. it is a function of system states. Such systems are named close queuing systems.

A visual diagram of traffic control equipment servicing, as a mass servicing position, is presented in Figure 5.

The simplest case of closed queuing system will be considered. A two-state configuration of element considered has been assumed:

- in state 0 the element fulfils its function (it is operational) – state of using,
- in state 1 the element is damaged (it is not operational) – state of servicing.

The system consists of one piece of equipment and one service employee. For the sake of considerations clarity, the denotations have been given once more:

- probability that the equipment is operational at a given moment amounts to p_0,
- probability that the equipment is damaged at a given moment amounts to p_1,
- intensity of equipment damage amounts to λ (the ratio of the number of defects in a given interval to the full time of equipment operation),
- intensity of servicing (performing repairs) amounts to μ (ratio of the repairs number to the full time of repairs duration).

The graph of states and transitions is presented in Figure 6.

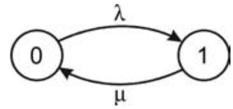

Figure 6. Graph of transitions between the state of being operational and damage.

1 piece of equipment,

1 service employee

where:

0 – means that the system is working properly, i.e. the equipment does not require a repair (it is operational),

1 – means that the equipment has been damaged and requires a repair.

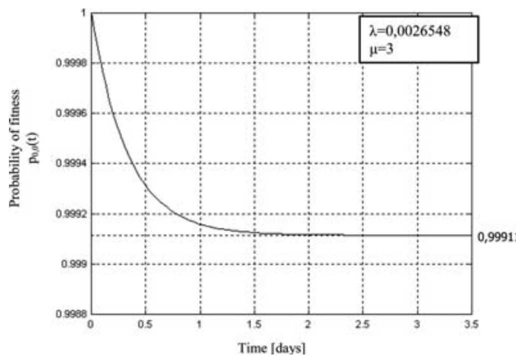

Figure 7. Availability of the system.

When resolving this system we will obtain

$$p_1(t) = \frac{\lambda}{\lambda+\mu}\left[1 - e^{-(\lambda+\mu)t}\right] = \frac{\lambda}{\lambda+\mu} - \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}$$

$$p_1(t) = \frac{\lambda}{\lambda+\mu}\left[1 - e^{-(\lambda+\mu)t}\right] = \frac{\lambda}{\lambda+\mu} - \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}$$

Probability $p_0(t)$ defines so-called availability of the system $A(t)$. Availability $A(t)$ is a probability that the system is operational (usable) in the future, assuming it is operational at the initial moment. For the exemplify system the course of availability is presented[1] in Figure 7.

The limit value of availability is interesting

$$\lim_{t\to\infty} \mathrm{A}(t) = \frac{\mu}{\lambda+\mu}$$

which also defines system fitness in a steady state.

In example above only equipment repair was considered in servicing, while no preventive servicing (periodic inspections) was taken into account. Preventive servicing is a planned undertaking, carried out on an operational object to increase its reliability.

Inspection service allows earlier finding of defects (malfunctions), what enables preventing damages and increasing so-called availability of the system.

[1] for example for transport traffic control equipment, more specifically, for a signal

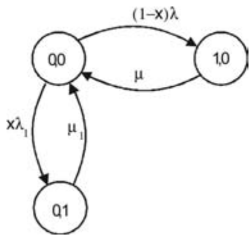

Figure 8. Graph of transitions between states of fitness (operational), damage and inspection.
1 piece of equipment,
1 service employee.

Introducing a possibility to carry out (from time to time) surveys and inspections of a given piece of equipment the graph of transitions (similar to the graph in Figure 6) will look as in Figure 8. State 00 is the state of using (availability), and the other two states – servicing: state 10 – a component is damaged and under repair, state 01 – the component is under inspection.

Intensity of equipment damage amounts to λ, while intensity of repair request servicing amounts to μ. Inspections intensity has been denoted by λ_1, while intensity of inspection request servicing, for each service employee, amounts to μ_1.

Resolving this system we obtain

$$p_{0,0}(t) = \frac{1}{\alpha-\beta}\left(\alpha e^{-\alpha t} - \beta e^{-\beta t}\right) - \frac{\gamma}{\alpha-\beta}\left(e^{-\alpha t} - e^{-\beta t}\right)$$
$$+\frac{\delta}{\alpha\beta(\alpha-\beta)}\left[(\alpha-\beta)+\beta e^{-\alpha t} - \alpha e^{-\beta t}\right]$$

where:

$$A = \lambda + \lambda_1 + \mu + \mu_1$$
$$B = A^2 - 4C$$
$$C = \mu\mu_1 + \lambda\mu_1 + \lambda_1\mu$$
$$\alpha = \frac{A-\sqrt{B}}{2}$$
$$\beta = \frac{A+\sqrt{B}}{2}$$
$$\gamma = \mu + \mu_1$$
$$\delta = \mu\mu_1$$
$$\alpha + \beta = A$$
$$\alpha - \beta = -\sqrt{B}$$
$$\alpha\beta = C$$

Probability $p_{0,0}(t)$ defines also so-called availability of the system $A(t)$. For the exemplify system the course of availability is presented in Figure 9.

Boundary availability, specifying system availability in a steady state

$$\lim_{t\to\infty} A(t) = \frac{\delta}{\alpha\beta} = \frac{\mu\mu_1}{\mu\mu_1 + \lambda\mu_1 + \lambda_1\mu_1} = \frac{1}{1+\rho+\rho_1}$$

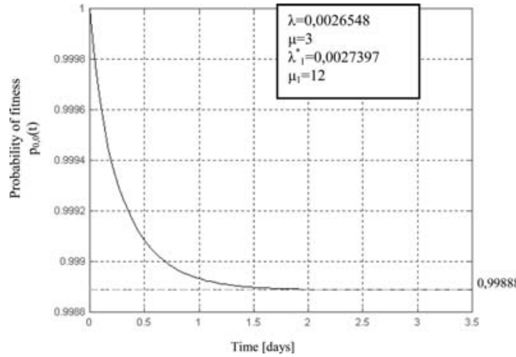

Figure 9. Availability of the system.

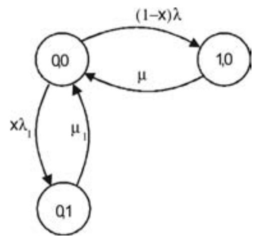

Figure 10. Graph of transitions between states of fitness (operational), damage and inspection, taking into account the inspection time.
1 piece of equipment,
1 service employee.

The case of system discussed in example above, which task – apart from repair of damaged equipment – consisted also of carrying out periodic inspections of the equipment, did not take into account the fact that at the moment of switching the equipment off for inspection this equipment was not working. After all, an assumption is made (Zamojski 1980) that object's reliability characteristics are functions of working time that is the object may be damaged only during work. Hence the time of defect occurrence gets "elongated" and thereby in calculations the share of inspection in total intensity of defects and inspections shall be considered. Percentage of this share is determined by the selection coefficient

$$x = \frac{\lambda_1}{\lambda + \lambda_1}$$

In other words, in the case analysed, the selection coefficient specifies

$$\frac{\text{average inspections number}}{\text{(to) average number of repairs and inspections}}$$

This modification results in a change in the transitions graph model from Figure 8. Modified transitions graph is presented in Figure 10.

Modified equation for probability that the system is operational in such a case is

$$p_{0,0}=\frac{1}{1+(1-x)\rho+x\rho_1}$$

or after substitution of coefficient x

$$p_{0,0}=\frac{1}{1+\left(\frac{\lambda}{\lambda+\lambda_1}\right)\rho+\left(\frac{\lambda_1}{\lambda+\lambda_1}\right)\rho_1}$$

and after expansion of relative intensities ρ and ρ_1

$$p_{0,0}=\frac{1}{1+\left(\frac{\lambda}{\lambda+\lambda_1}\right)\left(\frac{\lambda}{\mu}\right)+\left(\frac{\lambda_1}{\lambda+\lambda_1}\right)\left(\frac{\lambda_1}{\mu_1}\right)}=$$

$$=\frac{(\lambda+\lambda_1)\mu\mu_1}{(\lambda+\lambda_1)\mu\mu_1+\lambda^2\mu_1+\lambda_1^2\mu}$$

The analysis of the course of probability function of system availability (fitness) is interesting. Was this function monotonously increasing, this would mean full advisability of preventive actions (by the way, for monotonously decreasing function preventive actions would turn out "harmful"). In the event that this function has an extremum, the introduction of preventive actions affects object's reliability in different ways, depending on preventive actions frequency (number) and on their duration.

Seeking for optimum inspections intensity that is such inspections frequency for which probability of correct operation would reach a maximum value, a derivative of this expression shall be determined, hence

$$\frac{dp_{0,0}}{d\lambda_1}=\frac{\mu\mu_1\left[(\lambda+\lambda_1)\mu\mu_1+\lambda^2\mu_1+\lambda_1^2\mu\right]-(\lambda+\lambda_1)\mu\mu_1(\mu\mu_1+2\lambda_1\mu)}{\left[(\lambda+\lambda_1)\mu\mu_1+\lambda^2\mu_1+\lambda_1^2\mu\right]^2}$$

This derivative is equal zero, if

$$\mu\lambda_1^2+2\lambda\mu\lambda_1-\lambda^2\mu_1=0$$

$$\Delta=4\lambda^2\mu^2+4\lambda^2\mu\mu_1;\qquad \Delta\rangle 0\quad \text{always}$$

hence

$$\lambda_{1op}=\frac{-2\lambda\mu+2\lambda\sqrt{\mu^2+\mu\mu_1}}{2\mu}=\lambda\left(\sqrt{1+\frac{\mu_1}{\mu}}-1\right)$$

$$=\lambda\left(\sqrt{\frac{\mu+\mu_1}{\mu}}-1\right)$$

Checking, what is the condition for probability of system availability (fitness) with inspections service to be higher than in the case of only repair service, consists in comparing appropriate expressions

$$\frac{1}{1+\frac{\lambda^2}{(\lambda+\lambda_1)\mu}+\frac{\lambda_1^2}{(\lambda+\lambda_1)\mu_1}}\rangle\frac{1}{1+\frac{\lambda}{\mu}}$$

The condition to satisfy this inequality is that

$$1+\frac{\lambda}{\mu}\rangle 1+\frac{\lambda^2}{(\lambda+\lambda_1)\mu}+\frac{\lambda_1^2}{(\lambda+\lambda_1)\mu_1}$$

$$\lambda(\lambda+\lambda_1)\mu_1\rangle\lambda^2\mu_1+\lambda_1^2\mu$$

$$\lambda\mu_1\rangle\lambda_1\mu$$

that is that relative repairs intensity is higher than relative inspections intensity

$$\rho\rangle\rho_1$$

Calculations of system fitness in the event of inspections optimisation consist, having considered the selection coefficient in calculations with "new" defects intensity coefficients λ^* and inspections intensity λ_1^*.

So the equipment defects intensity amounts then to

$$\lambda^*=\frac{\lambda^2}{\lambda+\lambda_1}$$

and the inspections intensity amounts then to

$$\lambda_1^*=\frac{\lambda_1^2}{\lambda+\lambda_1}$$

On the other hand, the intensity of repair request servicing amounts, as so far, to μ, and the intensity of inspection request servicing for each service employee amounts, as so far, to μ_1.

Resolving this system we obtain

$$p_{0,0}(t)=\frac{1}{\alpha-\beta}\left(\alpha e^{-\alpha t}-\beta e^{-\beta t}\right)-\frac{\gamma}{\alpha-\beta}\left(e^{-\alpha t}-e^{-\beta t}\right)$$
$$+\frac{\delta}{\alpha\beta(\alpha-\beta)}\left[(\alpha-\beta)+\beta e^{-\alpha t}-\alpha e^{-\beta t}\right]$$

where

$$A=\lambda^*+\lambda_1^*+\mu+\mu_1$$
$$B=A^2-4C$$
$$C=\mu\mu_1+\lambda^*\mu_1+\lambda_1^*\mu$$
$$\alpha=\frac{A-\sqrt{B}}{2}$$
$$\beta=\frac{A+\sqrt{B}}{2}$$
$$\gamma=\mu+\mu_1$$
$$\delta=\mu\mu_1$$
$$\alpha+\beta=A$$
$$\alpha-\beta=-\sqrt{B}$$
$$\alpha\beta=C$$

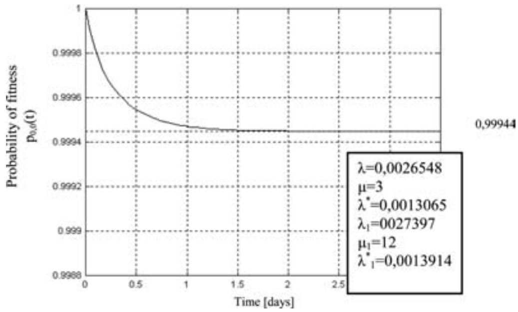

Figure 11. The course of availability in the event of application of the principle of inspections optimisation.

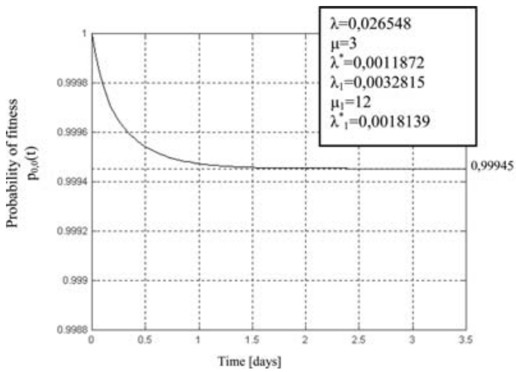

Figure 12. The course of availability in the event of carrying out inspections with optimum intensity.

Probability $p_{0,0}(t)$ defines also so-called availability of the system $A(t)$. The course of availability in the event of application of the principle of inspections optimisation is presented in Figure 11, while in the event of carrying out inspections with optimum intensity – Figure 12.

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4.6
Evaluation of main traffic congestion degree for restricted waters with AIS reports

Q. Hu, J. Yong & C. Shi
Shanghai Maritime University, Shanghai, China

G. Chen
Shanghai Maritime Administration, Shanghai, China

ABSTRACT: Traditionally, marine traffic congestion degree in restricted waters is usually deduced from traffic volume or traffic density. Both of which, however, can not be easily and accurately determined and can not fully reflect the traffic congestion degree. This paper uses the concept of main traffic flow velocity, which varies with the main traffic congestion from a statistics view, to determine the main traffic congestion degree in restricted waters. Main traffic flow velocity can be calculated by averaging the speeds of all ships equipped with an AIS transponder if the percentage of these ships over all vessels in the main traffic is great enough and they are well-distributed, and a fuzzy relationship is established to determine the traffic congestion degree under varying main traffic flow velocity. The concept of main traffic flow velocity provides a more intuitive and accurate way to evaluate the main traffic congestion degree of restricted waters than traffic density and traffic volume in certain situations, and can be easily implement.

1 INTRODUCTION

In recent years, shipping is developing rapidly over the world to meet the growing economic demands. Ships are getting greater, speedier, and more professional, and the number of ships improves dramatically. These factors make ports and channels more and more crowded and complicated, and the resulted traffic congestion or jam may enhance the risk of collision and decrease the traffic efficiency in a great extent. So the traffic congestion degree is becoming a more and more important parameter for traffic monitoring and management.

The concept of marine traffic congestion degree and its calculation, however, have not been well developed like in the road transportation domain. One important reason is the difficulty of collecting marine traffic information. Fortunately, more and more vessels have been equipped with AIS (Automatic Identification System), which can frequently broadcast own-ship's position, name, speed, course, size, etc. and so can facilitate marine traffic information collecting very much (Zhaolin W. & Jun Z. 2004).

With position reports of all ships in restricted waters, we can try to evaluate traffic congestion degree from the aspect of all ships. However, in restricted waters, there may be only partial vessels equipped with AIS while others may not for it's not compulsory for them according to the regulations. So in the context of this paper, we classify the ships into two category, one is the local small boat with or without AIS equipment, and the other is the general business ship of certain tonnage (for example, 500GT) or above, and ships belong to this category are usually equipped with AIS equipment. To ships of different category, the same traffic situation may mean different traffic congestion degree for they have different handling capacity and need different size of room for sailing. In this paper, we focus on the evaluation of main traffic congestion degree from the aspect of general business vessels by considering the existence of the small local boats.

This paper is organized as follows: Section 2 presents the features of marine traffic congestion, the traditional methods to determine it and their disadvantages. Section 3 proposes a fuzzy reasoning model to determine the main traffic congestion degree with main traffic flow velocity. Section 4 illuminates the method to calculate the main traffic flow velocity with AIS reports. Finally, main conclusion and discussion are offered in section 5.

2 MARRINE TRAFFIC CONGESTION FEATURES AND TRADITIONAL DESCRIPTION OF TRAFFIC CONGESTION DEGREE

At present, there is no definite definition of traffic congestion degree of restricted waters. In fact, marine traffic congestion always exists and can be manifested as:

1. With low sailing velocity and speeding up and down frequently.

2. With disorder navigation.
3. With too many vessels blocked in the restricted waters.

From the domestic and international research of marine traffic, it is found that marine traffic engineers prefer to use traffic density or traffic volume to determine traffic congestion degree (Yan L. et al. 2007 & Yansong G. & Zhaolin W. 2001).

Traffic density is the instant average quantity of the vessels per unit area in the surveyed waters, while traffic volume is the number of vessels through a certain waters during a certain time period (Zhaolin W. & Jun Z. 2004). Both traffic density and traffic volume can not describe the above 1) and 2) features of marine traffic congestion. Besides that, there are two other major disadvantages when traffic density and volume are applied to determine the marine traffic congestion degree.

1. It is not convenient to get the source data for calculating traffic density or volume. Manual or semi-automatic traffic survey, radar observation and aerial photography are generally needed.
2. Ships of different sizes need to be unified when calculating traffic density or volume, and the unification can not be done accurately.

So traffic density or volume is not a perfect parameter to determine traffic congestion degree.

3 A FUZZY EVALUATION MODEL OF MAIN TRAFFIC CONGESTION DEGREE BASED ON MAIN TRAFFIC FLOW VELOCITY

It is well known that traffic congestion degree can be determined by average velocity on road, such as: smooth traffic means that the average velocity is more than 30 kilometers per hour, normal traffic means that the average is between 20 and 30 kilometers per hour, crowed traffic means that the average is between 10 and 20 kilometers per hour and blocking traffic means that the average velocity is not more than 10 kilometers per hour or maybe nearly zero (Huapu L. & Janwei W. 2003).

Similar to road traffic, when the traffic in restricted waters is not congested, vessels can sail fast to the upper limit, while congested, vessels can only move slowly or even stop. Based on this similarity, this paper tries to propose a new evaluation method for marine main traffic congestion degree by using average velocity of vessels in the main traffic or main traffic flow velocity. Because the congestion is a fuzzy concept, a simple fuzzy inference system to calculate the congestion degree with traffic flow velocity as the input is designed (Khaled H. & Shinya K. 2002).

3.1 *Fuzzy inference system*

Fuzzy inference system, based on fuzzy set theory, fuzzy rule of If-then and fuzzy inference, contains

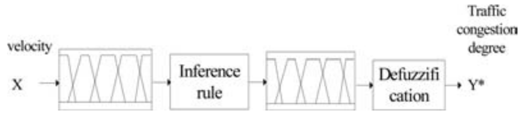

Figure 1. General structure of fuzzy inference system.

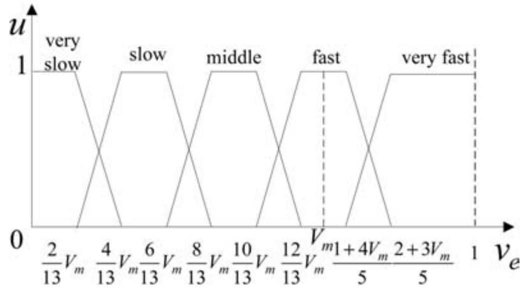

Figure 2. Membership function of traffic flow velocity.

three parts: 1) many fuzzy rules of If-then; 2) database for defining membership function; 3) inference engineering to get fuzzy results by input and fuzzy rules (JANG J S R. 1997). Figure 1 shows the general structure of a fuzzy inference system.

3.2 *Building fuzzy sets of traffic flow velocity and traffic congestion degree and their membership function*

Considering people's evaluating scale, the fuzzy sets can be set as: traffic flow velocity = {"very fast", "fast", "middle", "slow", "very slow"}, traffic congestion degree = {"blocking", "crowed", "not steady", "normal", "smooth"}

Figure 2 shows the membership function of the traffic flow velocity, wherev_e is the ratio of the current traffic flow speed and the free speed and $v_e \in [0, 1]$, and V_m is the ratio of the designed speed or the recommended speed for prevailing weather condition and normal traffic and the free speed.

Given v_e and the membership function of traffic flow velocity, we can determine the linguistic value of v_e by finding the linguistic value on which v_e gets the max membership. For example, if $u_{very\ slow}(v_e) = 0.6$ and $u_{slow}(v_e) = 0.4$, the linguistic value of v_e is *very slow*.

Figure 3 shows the membership of traffic congestion degree (TCD), which is quantified between 0 and 1, where 0 means traffic state is jam and 1 simplifies that it is very smooth in the waters.

3.3 *Fuzzy inference rule of the evaluation*

Here the fuzzy inference rule between traffic flow velocity and traffic congestion degree should be:

– If traffic flow velocity is "very fast", then traffic congestion degree is "smooth", and given v_e, $u_{very\ fast}(v_e) = u_{smooth}(v_e)$.

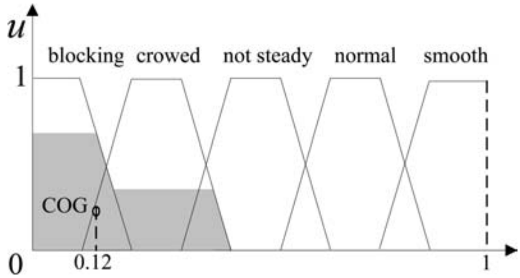

Figure 3. Membership function of traffic congestion degree.

Table 1. Fuzzy set mapping between traffic congestion degree and traffic flow velocity.

Grade	Traffic congestion degree	Membership of traffic flow velocity
1	smooth	very fast
2	normal	fast
3	not steady	middle
4	crowed	slow
5	blocking	very slow

– If traffic flow velocity is "fast", then traffic congestion degree is "normal", and given v_e, $u_{fast}(v_e) = u_{normal}(v_e)$.
– If traffic flow velocity is "middle", then traffic congestion degree is "not steady", and given v_e, $u_{middle}(v_e) = u_{not}$ steady (v_e).
– If traffic flow velocity is "slow", then traffic congestion degree is "crowed", and given v_e, $u_{fast}(v_e) = u_{crowed}(v_e)$.
– If traffic flow velocity is "very slow", then traffic congestion degree is "blocking", and given v_e, $u_{very\ slow}(v_e) = u_{blocking}(v_e)$.

Table 1 shows the mapping relationship between the fuzzy sets of traffic flow velocity and traffic congestion degree.

Here velocity has been divided into five grades and every grade is measured by designed speed Vm, which has considered influential factors of velocity, such as, visibility and can change a lot under different weather condition.

3.4 *Defuzzification*

As the output of fuzzy inference system is fuzzy, it is necessary to map the fuzzy congestion degree into a concrete value, which is called defuzzification. There are five defuzzification techniques and the most typical one is center of gravity (COG) (JANG J S R. 1997), which is used in the context of this research.

For example, if $u_{very\ slow}(v_e) = 0.6$ and $u_{slow}(v_e) = 0.4$, then $u_{blocking}(v_e) = 0.6$ and $u_{crowed}(v_e) = 0.4$, and finally the defuzzification value y* is 0.12 as figure 3 shows.

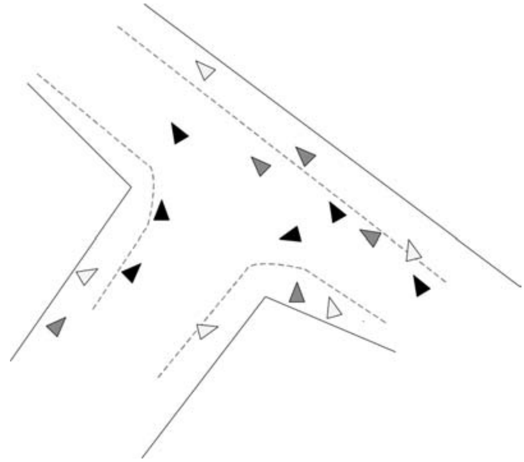

Figure 4. Schematic diagram of marine traffic, where black triangles stand for the ships equipped with AIS and in the main traffic, gray triangles present the ships without AIS, while white triangles signify local traffic ships with AIS.

4 MAIN TRAFFIC FLOW VELOCITY CALCULATION WITH SPEED INFORMATION PROVIDED BY AIS REPORTS

Generally, traffic flow velocity can be calculated by equation (2), where *n* means the total number of ships in an investigated waters and v_i means the current speed of *i*-th ship.

$$\overline{v} = \frac{\sum_{i=1}^{n} v_i}{n} \quad (1)$$

When we use equation (2) to calculate the main traffic flow velocity with the information provided by AIS reports, we shall note that not all ships in an investigated waters is equipped with AIS transponder, so the total number of ships can not be acquired.

In this paper, we regard each ship with AIS transponder in the main traffic as a sampling sensor, so if the percentage of these ships over all ships in the main traffic is great enough and they are well-distributed, the average speed of these ships will be able to reflect the traffic congestion degree.

For example, in Figure 4, we regard the average speed of all black vessels as the main traffic flow velocity. All white vessels are ignored because they are not in main traffic, and their speeds are not closely related to the traffic congestion degree for they may at anchor, berthing, etc.

5 CONCLUSIONS AND DICUSSION

This paper proposed to apply the concept of main traffic flow velocity to determine the main traffic congestion degree in restricted waters. Main traffic flow velocity is calculated by averaging the speed of all ships equipped with AIS transponders in the main traffic. A fuzzy inference model was built to determine the main traffic congestion degree under varying main traffic flow velocity. Comparing to traffic volume or density, the concept of main traffic flow velocity provides a more intuitive and accurate way to evaluate the main traffic congestion degree of restricted waters in certain situation, and can be easily implement.

The more percentage of ships equipped with AIS transponders in the main traffic is, the more reasonable the evaluating result given by the method proposed in this paper is. For the restricted waters where the percentage is not determinable, there are two conditions shall be satisfied before applying the method proposed in this paper: (1) the percentage of vessels with AIS transponder over all ships in the main traffic is great enough, and (2) the ships are well-distributed. The lower limit of the percentage and how to determine whether the ships are well-distributed shall be further studied. Besides that, traffic volume or density may be combined with traffic flow velocity to make the evaluation. We also have plans to apply clustering method to determine the limits between congested waters and smooth waters, and to render the marine traffic congestion degree on the Web sea map to facilitate ship owners and marine safety authorities to monitor the traffic.

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4.7
Computer vision and ship traffic analysis: Inferring maneuver patterns from the automatic identification system

K.G. Aarsæther & T. Moan
Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT: The Automatic Identification System has proven itself as a valuable source for ship traffic information. Its introduction has reversed the previous situation with scarcity of precise data from ship traffic and has instead posed the reverse challenge of coping with an overabundance of data. The number of time series available for ship manoeuvring analysis has increased from tens, or hundreds, to several thousands. Sifting through this data manually, either to find the salient features of traffic, or to provide statistical distributions of decision variables is an extremely time consuming procedure. In this paper we present the results of applying computer vision techniques to this problem and show how it is possible to automatically separate AIS data in order to obtain traffic statistics and prevailing features down to the scale of individual manoeuvres and how this procedure enables the production of a simplified model of ship traffic.

1 INTRODUCTION

Analysis of ship traffic receives focus as the awareness of the risk it poses to the environment is increased. The analysis is not only motivated by the desire to quantify risk, but also to understand the effect of changes to the fairway and to propose improvements to harbor areas and inland waterways. Analysis of ship traffic has been hindered by a scarcity of data, requiring specialized installations or equipment for data collection. This scarcity has prompted studies that rely on synthetic ship maneuvering data from simulators (Hutchinson 2003) and (Merrick 2003). While simulator studies provides valuable insights, through high sample rates, controlled environment and absence of noise, they make compromises on either the number of passages with the use of human operators in full-mission simulators, or on accuracy by eliminating the human element and relying on fast-time simulators with autopilot algorithms.

We will in this paper show how the introduction of the Automatic Identification System (AIS) for ships can help in both providing a readily available data source for traffic analysis, and how analysis of this data can be employed to generate statistics of traffic conditions, estimate maneuver plans and parameters as inputs to fast-time simulator studies.

The use of AIS in marine traffic analysis is not a new concept. (Gucma 2007) used AIS data to estimate the occurrence of accidents in the Baltic Sea by identifying the major traffic flows using AIS records of journeys. Little work has been done to apply AIS to analysis on the scale of maneuvers in a smaller or constrained area to derive the exhibited maneuver patterns. The area around the harbor of Risavika in southwestern Norway was selected as a case study. This area was selected since the presence of island formations and the coastline should impose a structure on the ship traffic. Information about all the navigational markings in the area was obtained from the Norwegian Hydrographic Service and contained data for position, type and identifiers for all publicly maintained navigational aids in the area. The area with AIS position reports and navigational markings indicated is shown in Figure 1.

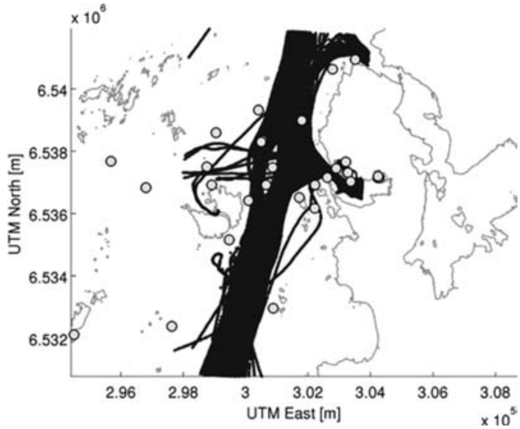

Figure 1. Risavika harbor with AIS position reports and navigation markers indicated.

The small-scale analysis benefits from the large volume of data available, but the size of the data sets involved makes analysis more demanding. At this level the analysis method must take into account the alternate routes through the area and the possibility of harbors.

The introduction of AIS has replaced the previous scarcity of ship traffic and maneuver data with an overabundance. Whereas one previously had to construct limited shore based measurement systems with limited lifespan or rely on data from a selected set of vessels with logging equipment, AIS provides a continuous stream of information of the position and speed all AIS enabled vessels in range. The system provides position and speed updates on predefined intervals depending on vessel speed and maneuver situation with a sample-rate varying from 3 seconds for high speed or turning vessels to 15 min for ships at anchor. The instantaneous information density varies naturally with the traffic density of the area, but if one considers past data, the amount of information to be shifted through and analyzed is considerable. The ability to analyze, and the capabilities of the techniques employed, will determine the quality of information about ship traffic extracted from this new source of historic ship traffic data.

On this background we present a method based on computer vision techniques, which is capable of handling this increase in available data.

2 METHOD

Analyzing ship traffic is a two-stage process where the first task is to transform the collected data into a form that eases the final analysis. A method for transformation of AIS data frames to a collection of maneuvers presented is comprised of following stages:

- Reconstruction of vessel specific time-series from AIS data
- Sorting of time-series from geometric similarity of the position trace
- Subdivision of the geometric similar groups into groups with the same direction of travel

This process produces groups of time-series with similar maneuver patterns and direction of travel well suited for generation of statistics and further analysis. Further analysis of these groups can include:

- Traffic properties such as distribution of vessel velocity and spread
- Estimation of maneuver sequence and parameter statistics
- Estimation of the most probable navigation aid used for maneuver transitions

2.1 *Model for ship maneuvers*

The ship maneuvering process is represented as a sequence of basic maneuvers. The basic maneuvers are instantiated and appear as a recognizable maneuver pattern. The most basic subdivision of maneuver patterns is the distinction between constant course and course changing maneuvers. While these categories can contain variations in the strategies employed to obtain the desired result, the two groups are represents the simplest geometric model is the model ship maneuvering.

2.2 *AIS data collection*

Data frames from the Norwegian AIS stations in the area around the harbor of Risavika were collected for three months from April to June 2006. AIS data frames are marked with a time stamp and the vessel specific MMSI number and contains the vessels instantaneous position and speed if available.

The data was ordered by MMSI number and time to recreate the time-series for each vessel. The time-series was then split at significant discontinuities in time to handle the cases of vessels leaving the studied area or coming to rest in a harbor. The number of AIS position reports in the area was 512,533 and the position reports were reduced to 2763 time-series.

2.3 *Grouping of time-series*

Application of image registration techniques solves the laborious task of grouping the time-series form the geometric similarity of the position trace.

Image registration techniques (Zitova 2003, Brown 1992) is applied in medical imaging and production control, and can be explained as the process of comparing images mathematically to produce an objective measure of their similarity and to detect the presence of a-priori known objects. These techniques are well suited for sorting vessel trajectories from their geometry as the position trace in isolation forms a line in an otherwise empty space. The trace of a vessels position can be transformed into the form of a digital image by discretization of the reported position. The studied area was dividend into 75×75 m bins and the number of position in each bin was counted and stored in a matrix for each time series. This is the representation used for grayscale images in image analysis.

Application of image registration must account for the possible differences in image resolution, rotation and translation of the captured scene. These parameters are controlled due to the transformation of remotely sensed data into an image with controlled orientation and resolution, but the location of the imprint of the individual vessel traces introduces an unknown possible translation. An application of image registration to group geometric similar tracks must account for this displacement within each group, but a global compensation will introduce errors, as it will detect similar position traces of similar form, but of very different location.

To reduce processing time the sorting of position traces was divided into a coarse and detailed analysis. The coarse analysis simply looked at the correspondence of track images without accounting for possible translations. If two images were deemed similar, future comparison was done with the mean track of the two. The coarse analysis left a large number of small groups, which were used as inputs to the detailed analysis. The detailed analysis made use of numerical optimization to find the optimum level of similarity between the groups. The cross-correlation between two images, where one has a translation (u,v) in (x,y) direction was used as an objective function and is seen in Equation (1).

$$CCR(u,v) = \frac{\sum_x \sum_y T(x,y) \cdot I(x-u, y-v)}{\max(\sum_x \sum_y T(x,y), \sum_x \sum_y I(x-u, y-v))} \quad (1)$$

where T = reference image matrix and I = the test image matrix with translation (u,v). The cross-correlation defined in Equation (1) is only valid for integer values (u,v) so a 3D interpolation method from (Vetterling 2007) was implemented to provide a continuous formulation of the cross-correlation. The interpolation routine allows standard numerical optimization strategies, such as steepest descend, to be applied to find the maximum correlation between two images. The cross-correlation was used to refine the grouping obtained by the coarse method by an iterative process where groups which showed a maximum correlation where combined.

The final operation on the sorted time series was to split each geometrically similar group into direction specific groups by considering the angle between the start and end points of each time-series.

2.4 *Group maneuver identification*

The time-series reconstructed from AIS have heterogeneous sample rates, within the geometric similar group, and even within the individual time-series. This necessitates a transfer of individual time series data to a common representation, which compensates for the variations in sample-rates. The properties of the time series group was estimated from 100 evenly spaced control points. The control points were computed as the mean points of 100 evenly spaced points for each time-series belonging to the group. Mean perpendicular vectors to the mean path were calculated in conjunction with the control points and used to establish mapping of the time-series indices to the control points by finding the intersection between the time-series trace and the perpendicular vectors.

The sequence of maneuvers in a group was tracked by the curvature of the vessels trajectory. The curvature of the vessel trajectories in each time series was computed by considering the x and y coordinate as signals in the time (Aarsæther 2007) as seen in Equation 2.

$$\kappa = \frac{\dot{x}\ddot{y} - \dot{y}\ddot{x}}{\left(\dot{x}^2 + \dot{y}^2\right)^{3/2}} \quad (2)$$

A polynomial was fitted locally to the x and y signals in time to provide well-defined derivatives for curvature calculation. The curvature of each time series was transferred to the group by the index to control point mapping. The group curvature is then calculated from the median of the group curvature at each control point. The individual turn and straight sections of the group are identified by an ad-hoc two-stage filtering based on statistics. The mean value, μ, and standard deviation, σ, are calculated and the points of the group curvature curve that falls outside the region defined by $\mu \pm 2\sigma$ are defined as belonging to a turn section, μ and σ are recalculated for the remaining points and the process repeated once more. Contiguous regions are identified as turn and straight segments.

The indentified turns in the group curvature only provide information about the median straight and turn behavior, to extend the analysis to the parameters of the maneuver model and to provide statistics demands data for the identified sections from each time-series. The translation between the turn sections of the median path to the individual time series is not well defined as the map of positions to control points. Variations in curvature can occur at different positions along the path and it is the sequence of maneuvers that is of interest. The turn sections of the median curvature were isolated and transferred to an image representation using the same procedure as for the position trace. The image representations of the individual turn sections were then matched to a section of the time-series by optimization of the similarity between the turn image from the group curvature and the time-series curvature. This identifies the locations of the turn sections in the individual time-series and enables the extraction of statistics based on the maneuver progression of the individual vessels instead of relying on geometric areas or indices from the group curvature to extract data.

2.5 *Statistics of time-series groups*

Statistics for each time-series group was calculated at the intersection between straight ant turn sections. The sections of the individual time-series sections were transferred to the group sections by mapping the turns in a time-series to the corresponding turn numbers in the group. Variables were according to section type

- Turn section: extreme, median & mean curvature and median speed over section
- Straight section: average course angle over section, offset from median path at both endpoints and median speed over section

2.6 *Identification of navigational aids*

The identification of the most used navigational aids is dependent on the location of the border points between the straight and circular sections of the ships path in relation to the navigational markings in the environment.

The identification of the most probable navigational aid is more error prone than processing of AIS data since the result is directly influenced by the choice of criterion used to identify the aid used in each time-series. The identification criterion used is based on ship-handling theory, where navigation references are preferred if the bearing from the turn initiation point to the reference is close to parallel with the future course. The angle to all the navigational markings in the area was calculated for each turn initiation, and the marking with a bearing closest to the course at the turn exit was chosen as the most navigation mark in use.

3 RESULTS

The entire collection of AIS data frames was stored in an SQL database for easy management and extraction. Data frames was selected according to area and ordered by time and MMSI number. The image registration routines and data processing was implemented in MATLAB. The time-series was converted to images with the *hist3* function of Mathworks' "statistics toolbox" for MATLAB, and optimization of image similarity was handled by the constrained optimization function *fmincon* from "optimization toolbox" with gradient descend search.

3.1 *Separation of traffic*

Traffic clustered in seven groups, in addition groups consisting of one to five time-series was also present, but these have lack the numbers required to proclaim them as traffic-groups. Of the seven major groups one group consisted of AIS position reports of vessels at anchor in the harbor and was excluded from further analysis. The number of time-series in the other six groups, as well as the breakdown in directional groups, is seen in Table 1

The geometric group of time-series belonging to the five first groups is seen in Figure 2–6. Time-series

Table 1. Distribution of time-series into groups of geometric similarity.

Group	Total	Direction 1	Direction 2
1	1017	443	573
2	809	436	373
3	76	16	60
4	552	240	311
5	17	4	13
6	11	2	9

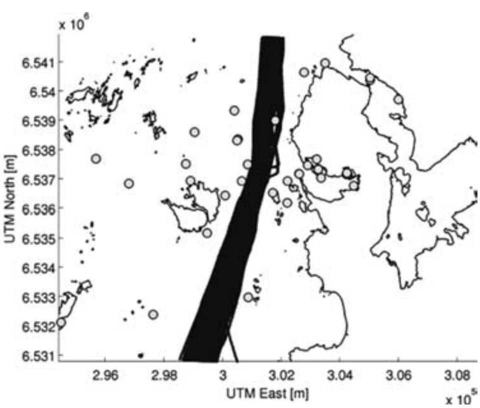

Figure 2. Position trace of time-series in group 1.

group six is excluded since it is only a small component intersecting with the areas northeast corner.

For further analysis based on statistics, only the three densest populated geometric groups should be considered. This is due to the uncertainty associated with statistical analysis of small populations and to avoid drawing conclusions on a weak statistical base.

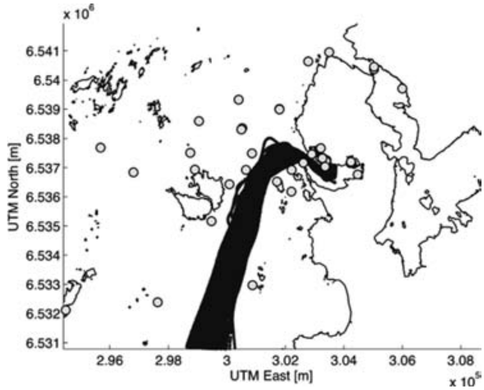

Figure 3. Position trace of time-series in group 2.

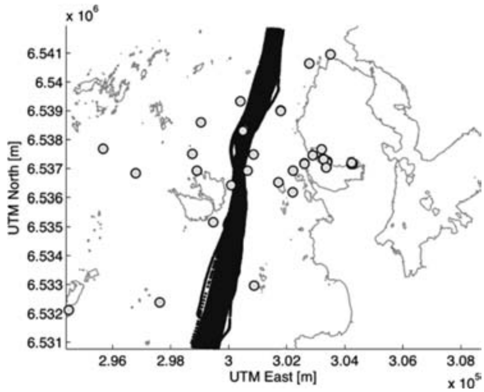

Figure 4. Position trace of time-series in group 3.

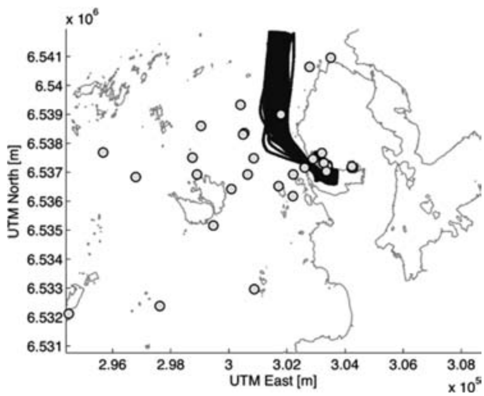

Figure 5. Position trace of time-series in group 4.

3.2 *Maneuver sequences and statistics*

Maneuver sequences were identified and statistics for traffic properties and maneuver parameters were produced. The measured variables were fitted both to the normal and skew-normal (Azzalini 1985) probability distributions. The skew-normal distribution was introduced to compensate for expected skewness in the data that could severely influenced the accuracy of the

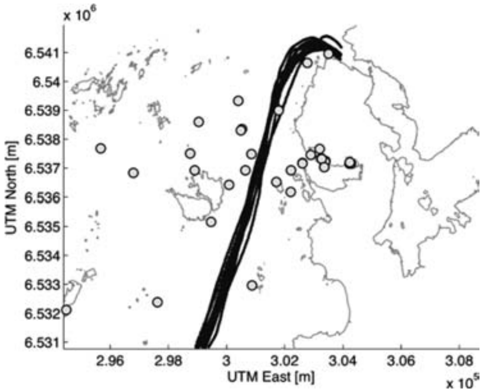

Figure 6. Position trace of time-series in group 5.

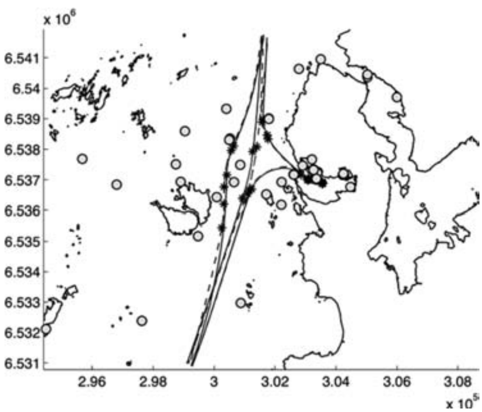

Figure 7. Median traffic paths with turn sections indicated.

normal fit. Statistic calculations and fitting of distributions was performed with "R" with the "MASS" and "SN" statistic libraries. The median paths with turn section border points indicated are shown in Figure 7.

Due to space limitations a full treatment is only possible for one direction in one of the sample groups. The direction group 1 of sample group 4 is analyzed further. The parameters of fitted skew normal probability distributions of the traffic parameters are shown in Table 2.

From Table 2 it is possible to track the increase in both the vessel speed and spread from median position from the harbor area to the edge of the studied area. The curvature of the turn sections shows that the course-changing maneuver in section 3 can be modeled as a turn-circle maneuver with a radius of approximately 1.25 nautical miles.

The goodness of fit between the data from the AIS time-series and the skew-normal probability distribution function can be seen in Figures 8–10 where the empirical density function is plotted together with the fitted distribution functions.

3.3 *Navigational aids*

The identification of navigational aids made use of the information of navigational markings in the area as provided by the Norwegian hydrographic Service, but excluded markings consisting of iron poles used

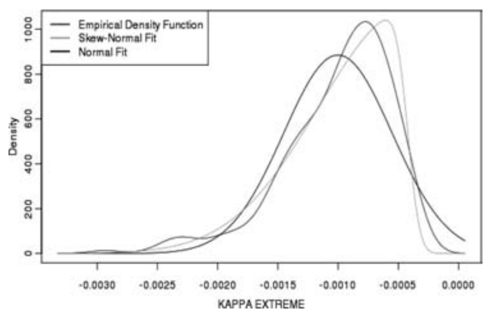

Figure 8. Extreme value of curvature during turn.

Table 2. Parameters for traffic statistics for group 4, direction 1.

Section	Type	Variable		Location	Scale	Shape
1*	Turn	k.ext	[1/m]	−5.20e-4	2.75e-3	−14.6
		speed	[kn]	5.5	3.42	3.05
2	Straight	offset start	[m]	19.7	37.3	−1.13
		offset end	[m]	−37.5	64.6	0.85
		course	[rad]	−0.90	0.08	1.89
		speed	[kn]	7.9	3.7	2.51
3	Turn	k.ext	[1/m]	−4.21e-4	7.36e-4	−9.34
		speed	[kn]	8.3	4.15	3.12
4	Straight	offset start	[m]	−100.4	155.0	1.74
		offset end	[m]	−120.6	163.9	2.36
		course	[rad]	0.012	0.053	1.18
		speed	[kn]	8.5	4.30	3.48

* Start section inside harbor

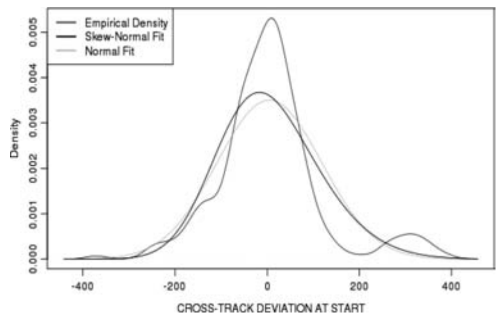

Figure 9. Offset from median position at end of turn (start of next section).

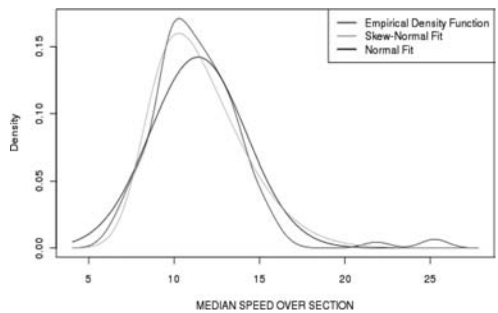

Figure 10. Median speed over turn section.

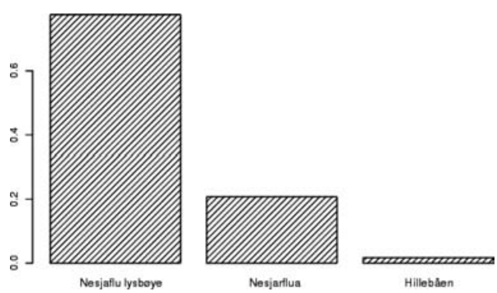

Figure 11. Relative frequency of identified used navigational aid.

to mark shallows. This left only lighthouses and light buoys. Identification showed good consistency with only two to three objects contributing the majority of observed identifications. For the initiation of the turn in section three seen in Table 2 the relative contributions are shown in Figure 11.

From Figure 11 it is apparent that the navigational markings at the location "Nesjaflua" dominates as the most probable navigational mark. The distribution of course angles between the two most used markings is seen in Figure 12, the overlapping notches in the plot indicates that there is no statistically significant difference between the median apparent angle to the markings.

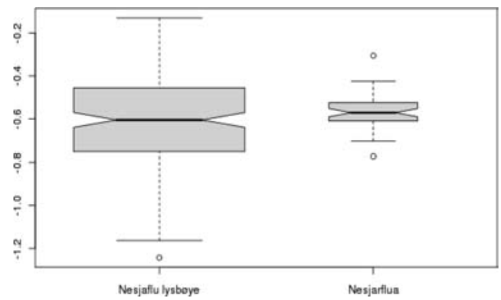

Figure 12. Distribution of apparent angle to landmark, box width indicates sample size.

4 CONCLUSION

It has been demonstrated that image registration techniques can provide an efficient and accurate solution to the problem of shifting through large amounts of position reports from AIS and prepare them for analysis in groups. Image registration also overcomes the problem of identification of turn maneuvers in individual time-series. The group analysis of the AIS position reports enables the identification of statistical parameters for the traffic flow, as well as of probable navigational marks for turn initiations and turn radi.

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4.8 Possible method of clearing-up the close-quarter situation of ships by means of Automatic Identification System

V.M. Bukaty & S.U. Morozova
Baltic Fishing Fleet State Academy, Kaliningrad, Russia

ABSTRACT: The tonic discussed is an non-traditional approach to the earliest possible clearing up of the head-on situation, consisting in defining the time of simultaneous approach to same latitudes and longitudes, bearing in mind that the information about the ships' movement was received by means of Automatic Identification System. If the time the ships proceed to these latitudes and longitudes is the same the collision of the ships is unavoidable and by the time identified the head-on situation is immediately indicated. If the time is different the ships will not be able to reach the same point and the collision will be avoided. The attempts have been also made to evaluate the minimal admitted inequality of time when the ships' safe passage without maneuvering is considered possible.

This method is rather attractive because it does not require any additional measurements and it is not necessary to attract the Officer-in-Charge away from his main responsibility – to control the situation round the ship.

1 INTRODUCTION

Earlier we were discussing non-traditional approach to the earliest possible clearing up of the head-on situation the essence of which is in defining the time of simultaneous approach the same latitudes and longitudes taking into account the fact that the information about ship's movement was received by means of Automatic Identification System (AIS) (Bukaty, V. M. 2005. Research…; Bukaty, V. M. 2006. Non-traditional…)

2 FUNDAMENTALS OF METHOD

When using AIS at a given instant of time t_1 positions φ_{g1} and λ_{g1} speed v_g and track angle TA_g of a given vessel and positions φ_{o1} and λ_{o1}, speed v_o and track angle TA_o of an oncoming vessel (target). At instant of time t_2 positions φ_{g2} and λ_{g2} of the given vessel and positions φ_{o2} and λ_{o2} of the oncoming vessel will be:

$$\varphi_{g2} = \varphi_{g1} + v_g(t_2 - t_1)\cos TA_g = \varphi_{g1} + v_g t \cos TA_g \quad (1)$$

$$\lambda_{g2} = \lambda_{g1} + v_g(t_2 - t_1)\sin TA_g \sec\varphi_m = = \lambda_{g1} + v_g t \sin TA_g \sec\varphi_m (1) \quad (2)$$

$$\varphi_{o2} = \varphi_{o1} + \mathrm{v_o}(\mathrm{t_2} - \mathrm{t_1})\cos \mathrm{TA_o} = \varphi_{o1} + \mathrm{v_o t} \cos \mathrm{TA_o} \quad (3)$$

$$\lambda_{o2} = \lambda_{o1} + v_o(t_2 - t_1)\sin TA_o \sec\varphi_m = = \lambda_{o1} + v_o t \sin TA_o \sec\varphi_m \quad (4)$$

In equations (1), (2), (3) and (4) $t = t_2 - t_1$, φ_m – an average latitude between vessels.

If in a period of time t the vessels are in the same position it will mean that $\varphi_{g2} = \varphi_{o2}$, $\lambda_{g2} = \lambda_{o2}$. Then taking into account (1), (2) and (2), (4) we can put it as:

$$\begin{aligned} &\varphi_{g1} + v_g t_\varphi \cos TA_g = \varphi_{o1} + v_o t_\varphi \cos TA_g \\ &\lambda_{g1} + v_g t_\lambda \sin TA_g \sec\varphi_m = \\ &= \lambda_{o1} + v_o t_\lambda \sin TA_o \sec\varphi_m \end{aligned} \quad (5)$$

In equations (5) we provided the value t with indices "φ" and "λ" to indicate the time of vessels' reach the same latitude and longitude.

Equations (5) follows:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{v_g \cos TA_g - v_o \cos TA_o} \quad (6)$$

$$t_\lambda = \frac{\lambda_{t1} - \lambda_{o1}}{(v_g \sin TA_g - v_o \sin TA_o)\sec\varphi_m}. \quad (7)$$

If $t_\varphi = t_\lambda$, that is the vessels reach the same position simultaneously, the collision is unavoidable.

The value of $t_\varphi = t_\lambda$ then helps to obtain the time of meeting. If $t_\varphi \neq t_\lambda$, the vessels are not able to reach the same latitude and longitude simultaneously, that is they are not able to be in the same position and their meeting is impossible.

3 INDIVIDUAL CASES OF THE GIVEN METHOD

The analysis of (6) and (7) shows:

1 In head-on situation when vessels run the longitude they will reach the same latitude (meet) in a period

of time equal to:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{v_g + v_o}$$

and they will reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0}$$

2 When vessels run the longitude the same track one after another they will reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{v_g - v_o}$$

and reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0}$$

However, if $v_g < v_o$, vessels will reach the same latitude in a period of time equal to:

$$t_\varphi = -\frac{\varphi_{o1} - \varphi_{g1}}{v_g - v_o}$$

and reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0}$$

This will mean that the speed of the given vessel is lower than the speed of the target vessel.

Or, if $v_g = v_o$, vessels will reach the same latitude in a period of time equal to:

$$t_\varphi = \infty$$

and reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0}.$$

This will mean that that the speeds of vessels are equal.

3 In head-on situation when vessels run the latitude they will reach the same longitude (meet) in a period of time equal to:

$$t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g + v_o)\sec\varphi_m}$$

and reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{0}{0}$$

4 When vessels run the latitude the same track one after another they will reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sec\varphi_m}$$

and reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{0}{0}$$

However, if $v_g < v_o$

$$t_\lambda = -\frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sec\varphi_m}$$

and they will reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{0}{0}$$

It will mean that the given vessel is moving more slowly than the target vessel.

Or, if $v_g = v_o$

$$t_\varphi = \infty$$

and they will reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0}$$

This will mean that that the speeds of vessels are equal.

5 When vessels run different longitudes on reciprocal tracks they will reach the same latitude in a period of time equal to

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{v_g + v_o}$$

and they will reach the same longitude in a period of time equal to:

$$t_\lambda = \infty$$

6 When vessels run different longitudes on the same track they will reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{v_g - v_o}$$

and they will reach the same longitude in a period of time equal to:

$$t_\lambda = \infty$$

However, if $v_g < v_o$, vessels will reach the same latitude in a period of time equal to

$$t_\varphi = -\frac{\varphi_{o1} - \varphi_{g1}}{v_g - v_o}$$

and they will reach the same longitude in a period of time equal to

$$t_\lambda = \infty$$

It will mean that the given vessel is moving more slowly than the target vessel.

If $v_o = v_g$, vessels will reach the same latitude in a period of time equal to:

$$t_\varphi = \infty$$

and they will reach the same longitude in a period of time equal to:

$$t_\lambda = \infty$$

This will mean that that the speeds of vessels are equal.

7 When vessels run different latitudes on reciprocal tracks they will reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g + v_o)\sec\varphi_m}$$

and they will reach the same latitude in a period of time equal to:

$$t_\varphi = \infty$$

8 When vessels run different latitudes on the same track they will reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sec\varphi_m}$$

and they will reach the same latitude in a period of time equal to:

$$t_\varphi = \infty$$

However, if $v_g < v_o$, vessels will reach the same longitude in a period of time equal to:

$$t_\lambda = -\frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sec\varphi_m}$$

and they will reach the same latitude in a period of time equal to:

$$t_\varphi = \infty$$

It will mean that the given vessel is moving more slowly than the target vessel.

If $v_g = v_o$, vessels will reach the same longitude in a period of time equal to:

$$t_\lambda = \infty$$

and they will reach the same latitude in a period of time equal to:

$$t_\varphi = \infty$$

This will mean that that the speeds of vessels are equal.

9 When vessels meet head and head on reciprocal arbitrary tracks, they will reach the point of meeting in a period of time equal to:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{(v_g + v_o)\cos TA_g} = $$

$$= t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g + v_o)\sin TA_g \sec\varphi_m}$$

10 When the vessels run the same arbitrary tracks they will reach the point of meeting in a period of time equal to:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{(v_g - v_o)\cos TA_g} = $$

$$= t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sin TA_g \cos\varphi_m}$$

However, if $v_g < v_o$, vessels will reach the point of meeting in a period of time equal to:

$$t_\varphi = -\frac{\varphi_{o1} - \varphi_{g1}}{(v_g - v_o)\cos TA_g} = $$

$$= t_\lambda = -\frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sin TA_g \sec\varphi_m}$$

It will mean that the given vessel is moving more slowly than the target vessel.

If $v_g = v_o$, vessels will reach the point of meeting in a period of time equal to:

$$t_\varphi = \infty$$

$$t_\lambda = \infty$$

This will mean that that the speeds of vessels are equal.

11 When vessels run reciprocal arbitrary parallel tracks, they will reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{(v_g + v_o)\cos TA_g}$$

and they will reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g + v_o)\sin TA_g \sec\varphi_m},$$

however, there is always inequality $t_\varphi \neq t_\lambda$.

12 When vessels run the same arbitrary parallel tracks the times of their reach to the same latitude and the same longitude in general case is calculated by formulas (6) and (7). Here we can speak about different combinations of values t_φ and t_λ depending on relation of speeds ($v_g < v_o$, $v_g > v_o$, $v_g = v_o$),

vessels' position at the time instant t_1 ($\varphi_{g1} > \varphi_{o1}$ or $\varphi_{g1} < \varphi_{o1}$, $\lambda_{g1} > \lambda_{o1}$ or $\lambda_{g1} < \lambda_{o1}$) and values of track angles *TA*.

In this case negativity of one of the times and positivity of another or negativity of the both times mean that vessels will never reach the same latitude ($-t_\varphi$) or the same longitude ($-t_\lambda$), or will never reach the same latitude or the same longitude ($-t_\varphi$ and $-t_\lambda$)

13 When vessels run arbitrary tracks the time of their approach to the same latitude and the same longitude is calculated by formulas (6) and (7). If $t_\varphi = t_\lambda$, it will mean that vessels are going to meet; but if $t_\varphi \neq t_\lambda$ they will not meet.

14 When vessels run arbitrary tracks there can be situations when $t_\varphi = 0$ and $t_\lambda \neq 0$, or vice versa, $t_\lambda = 0$ and $t_\varphi \neq 0$, though vessels can simultaneously be at the same point. For example, it can happen when vessels at starting position are on the same latitude or the same longitude. Thus, if $\varphi_{g1} = \varphi_{o1}$, $\lambda_{g1} \neq \lambda_{o1}$ or $\varphi_{g1} \neq \varphi_{o1}$, $\lambda_{g1} = \lambda_{o1}$ and vessels run crossing tracks, (6) and (7) follow:
in the first case

$$t_\varphi = 0, \; t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g \sin TA_g - v_o \sin TA_o)\sec\varphi_m}; \quad (8)$$

in the second case

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{v_g \cos TA_g - v_o \cos TA_o}, t_\lambda = 0, \quad (9)$$

In both cases $t_\varphi \neq t_\lambda$, but meeting of vessels is not improbable. For example, if $\varphi_{g1} = \varphi_{o1} = 0°$, $v_g = v_o$, $TA_g = TA_o \pm 90°$, it is clear that vessels will meet despite the fact that $t_\varphi \neq t_\lambda$. In this case we can clear up the situation in the following way. By calculated value t_λ, if $t_\varphi = 0$, or by calculated value t_φ, if $t_\lambda = 0$, are calculated by the formulas:

$$\varphi_{t2} = \varphi_{t1} + v_t t_\lambda \cos TA_t, \quad (10)$$

$$\lambda_{t2} = \lambda_{t1} + v_t t_\varphi \sin TA_t \sec\varphi_m \quad (11)$$

Then t_φ and t_λ are calculated by formulas:

$$t_\varphi = \frac{\varphi_{t2} - \varphi_{t1}}{v_o \cos TA_o}; \quad (12)$$

$$t_\lambda = \frac{\lambda_{t2} - \lambda_{o1}}{v_o \sin TA_o \sec\varphi_m} \quad (13)$$

If calculated values t_φ (12) or t_λ (13) are equal to earlier calculated values t_φ (8) or t_λ (9), the vessels are going to meet. Otherwise they will not meet. For example, if $\varphi_{g1} = \varphi_{o1} = 0°$, $\lambda_{g1} = 0°$, $\lambda_{g2} = 0°10'$E, $\varphi_m = 0°$, $v_g = v_o = 10\,kts$, $TA_g = 45°$, $TA_o = 315°$, according to (8) $t_\varphi = 0$, $t_\lambda = 42$ min 25.6 sec. In accordance with this value t_λ according formula (10) $\varphi_{o2} = 0°05'$N. Then according to (13) we have $t_\lambda = 42$ min 25.6 sec. As $t_\varphi = t_\lambda$, the vessels in the given example are going to meet.

Similar example can be given for the case when $t_\varphi \neq 0$, and $t_\lambda = 0$. If $\varphi_{g1} = 0°05'$N, $\varphi_{o1} = 0°05'$S, $\lambda_{g1} = \lambda_{o1} = 0°$, $\varphi_m = 0°$, $v_g = v_o = 15$ kts, $TA_g = 135°$, $TA_o = 45°$, according to (8) and (9) $t_\lambda = 0$, $t_\varphi = 28$ min 17.1 sec. In accordance with this value t_φ by formula (11) is calculated $\lambda_{o2} = 0°05'$E. Then according to (13) we have $t_\lambda = 28$ min 17.1 sec. As $t_\varphi = t_\lambda$, the vessels in the given example are also going to meet.

4 CONCLUSION

It follows from the our analysis that:

1 The sign of the situation when vessels are meeting is the equality of the time of their reach to the same latitude or the same longitude in general case ($t_\varphi = t_\lambda$), or equality of uncertainty $\frac{0}{0}$ of one of the times of their approach the same latitude or longitude when the vessels run the latitude or longitude respectively
2 The sign of the situation when vessels run reciprocal parallel tracks in general case is inequality of times of their reach to the same latitude and longitude, both values of times being positive. The sign of the situation when vessels run reciprocal parallel tracks in particular case is infinity of times of their reach to the same latitude and longitude when running the latitude or longitude the target vessel is overtaking. If they are equal to infinity, vessels are moving at the same speed. At the same time if t_φ or t_λ are positive, the vessel is the given vessel is overtaking. If t_φ or t_λ are negative, the target vessel is overtaking. If $t_\varphi = \infty$ and $t_\lambda = \infty$, vessels are moving at the same speed.
3 The sign of the situation when vessels run the same parallel tracks in general case is inequality of times of their reach to the same latitude and longitude. If both values of the times are positive, the given vessel is overtaking. If they are negative, the target vessel is overtaking. If they are equal to infinity, vessels are moving at the same speed. At the same time if t_φ or t_λ are positive, the vessel is the given vessel is overtaking. If t_φ or t_λ are negativ, the target vessel is overtaking. If $t_\varphi = \infty$ and $t_\lambda = \infty$, vessels are moving at the same speed.

Realization of the non-traditional approach to clearing up the situation when vessels are meeting is possible with the help of automatic calculating device, information to which comes from AIS and results are presented in the form of messages on the display of ECDIS and in the form of warning sound signals about the threat of collision.

Non-traditional approach is in no way considered to be an alternative for the traditional way of assessment of head-on situation based on radar or AIS data and on making up relative plotting which allows to define a distance and shortest time of vessels meeting. We consider it to be an addition to the traditional method allowing to assess head-on situation in due time at distance between ships equal to operating distance of AIS (about 20 miles) without measurements and relative plotting, and consequently without distracting Officer of Watch from controlling the situation round the ship.

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Chapter 5. Navigational tools, systems and equipment

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

5.1 Development of a concept for bridge alert management

F. Motz & S. Höckel
Research Institute for Communication, Information Processing and Ergonomics, FGAN, Wachtberg, Germany

M. Baldauf
World Maritime University, Malmö, Sweden

K. Benedict
Hochschule Wismar University of Technology, Business and Design, Warnemünde, Germany

ABSTRACT: Modern ship bridges are highly-automated man-machine systems. Safe and efficient ship operations are dependent on the communication between humans and machines. This paper is dedicated to the general subject of integrated navigation and the specific field of the alert management on a ship's navigational bridge. It deals with investigations into the present situation on board of ships regarding the frequency and type of triggered alarms under real conditions. The conduction of empirical field studies is introduced and some of the gained results are presented and discussed. Finally the alert management concept of the performance standards for Integrated Navigation Systems (INS) is introduced and an approach for the reduction of CPA/TCPA alarm frequencies within INS/IBS is described.

1 INTRODUCTION

Modern ship bridges show a high degree of automation. A large amount of information concerning navigation, safety and security as well as the monitoring and control of the technical facilities on board are integrated in the operational displays on the bridge. With respect to the level of integration of the sensors, equipment, displays and assistance systems a modern ship bridge can be defined as a highly-complex man-machine system. As such the safety and efficiency of its handling is dependent on the communication between the human and the machines during the accomplishment of tasks. Humans can fulfill their assigned monitoring, control, and decision tasks most effectively, if the information flow between them and machines is adapted to the human skills and abilities (e.g., Lützhöft 2004). To support the mariner effectively, information should be presented task- and situation-dependent.

Associated with the high degree of automation and integration of systems and sensors on board is a proliferation of alarm signals on the bridge. Redundant and superfluous audible and visual alarms are appearing, without a central position for visualization and acknowledgement of alarms. That way alarms increase the seafarers' workload and lead to information overload (Earthy 2006). Alarm signals coming from various systems and sensors lead sometimes to a confusing and difficult manageable situation for the mariner, which is distracting him from his task to safely navigate the vessel.

The majority of marine accidents are associated with collisions and groundings – in terms of numbers as well as in terms of costs. While some accidents result from technical failures of one kind or another (e.g. structural, engine or steering failure), many are caused by navigational errors (Wadsworth 2005). Research indicates that a high percentage of collisions and groundings are due to direct human error (IMO 2008).

To enable the operator to devote his full attention to the safe navigation of the ship and to immediately identify any abnormal situation requiring action to maintain the safe navigation of the ship an alarm management harmonizing the handling, distribution and presentation of alarms on the bridge is necessary (Bainbridge 1983, Sheridan 1998).

For navigational alarms such an alarm management is introduced within the revised performance standards for integrated navigation systems (INS), which needs to be implemented for all INS installed after January 1st 2011. Additionally, the International Maritime Organization (IMO) decided to develop in the context of the revision of the performance standards for integrated bridge systems (IBS) a bridge alarm management system that comprises all alarms occurring on the bridge. A correspondence group coordinated by Germany was established to progress this work.

The importance of an alert management is recognized as well within the framework of the e-navigation strategy of the IMO (IMO 2008). As one high-level user need within the e-navigation strategy an alarm management system as accomplished in the revised performance standards for INS is identified.

To investigate the current situation of the management and presentation of all alarms appearing on ships' bridges a number of field studies were performed on board of vessels. The results of those studies were introduced in the work of the IMO correspondence group working on the development of performance standards for Bridge Alarm Management. Within this paper selected results of the investigations are presented as well as the conclusions drawn regarding the performance standards for Bridge Alarm Management which will be finalized at the 55th session of the IMO Subcommittee Safety of Navigation (NAV) in 2009. An approach for the reduction of the number of alarms is introduced.

The field studies were performed under the framework of a national Research and Development project funded by the German Ministry of Transport, Building and Urban Affairs, and under the European MarNIS-project, funded by the European Commission, Department for Energy and Transport.

2 FIELD STUDIES – METHOD AND SAMPLE

Field studies were carried out on board of six vessels: two ferries operating in the Baltic Sea, three container vessels (with container capacities of 6200 TEU, 5500 TEU and 7500 TEU) and a cruise vessel operating in the Mediterranean Sea. The aim of the field studies was to investigate the current occurrence of alarms on a ships bridge and their handling by the bridge team. As the management and presentation of alarms is influenced by the type of ship, the year of construction, the installed equipment and grade of integration, the sea area, the training and education of the crew as well as by the safety standards of the shipping company (Baldauf & Motz 2006), these factors were taken into account to obtain a profound database.

All alarm and warning messages occurring on the bridge were manually recorded. It was registered what kind of alarm occurred, when and where it was announced, how it was presented and how it was handled by the bridge team.

To compare the different bridges on each vessel the specific sensor systems in use for navigation (positioning, speed, track control, collision avoidance and so on) together with the configuration of the alarm thresholds were registered. Simple changes in the configuration and the settings of the alarm limits lead to an increase or decrease of the announced alarms.

A special focus was laid on the assumed dependencies of alarm frequencies from sea areas. For the purposes of the studies the navigational situations were defined based on collected experts' opinions as:

– "open sea" (no natural constraints/no artificial constraints),
– "coastal" (natural constraints/distance to coast less than 10 nm without harbor, pilotage, anchorage/ artificial constraints – e.g. TSS with established traffic lanes and recommended routes) and
– "confined" (with three different special cases: harbor, pilotage and anchorage).

Additionally interviews by means of a structured guideline were carried out to gather opinions, suggestions and remarks of navigators on the occurrence and presentation of alarms on the bridge, the handling of alarms and related operational problems.

The investigated vessels were built or reconstructed within the time span from 2001 until 2007. The ships' navigational bridges were provided with equipment from different manufacturers that was integrated and combined on a medium or high integration level.

The field studies were conducted on different times of the year during voyages in the Baltic Sea, in the Western Mediterranean Sea, in the North Sea and in the English Channel. Usually good weather conditions were experienced with low winds and calm sea. The average time of observation was 19 hours, with a minimum of 11 hours and a maximum of 27 hours.

3 FIELD STUDIES – RESULTS

3.1 *Alarm thresholds and adjustment of alarm announcement*

In the framework of the field studies it was recorded which settings the bridge team used for the triggering of alarms and warnings at the installed navigational equipment. It was assumed that the navigators would adjust the alarm thresholds and limit values to the different navigational situations and sea areas.

However the contrary was observed. On three of the six vessels no adjustments at all were made to the alarm thresholds and limit values – neither according to sea areas nor visibility conditions. On the remaining ships a change of the thresholds was rarely the case as well. One of the navigators adjusted the limits for CPA/TCPA (Closest Point of Approach/Time to CPA) in confined conditions to 0.5 nautical miles (nm) and 0 minutes (min) to practically switch off the alarms.

In general the thresholds for CPA alarms were set to 0.5 nm on five of the vessels with a TCPA limit of 6, 10, 12 or (twice) 15 minutes. On Ferry 2 the CPA/TCPA limits were set to 0.0 nm/0 min throughout the voyage.

Adjustments to the different navigational situations and sea areas were observed regarding the alarm announcement. The audible signaling of radar alarms was switched off from time to time on almost all vessels. Especially in confined conditions during departure and arrival, where a lot of targets appear on the radar, alarms (e.g. collision avoidance and lost target alarms) were not acoustically announced. On Ferry 2 the audible alarm announcement was switched off on both radars throughout the voyage.

3.2 *Dependencies on sea area*

One hypothesis of the investigations was that the frequency of alarms is dependent on the sea area in which

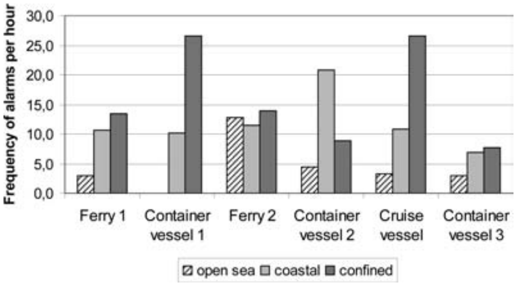

Figure 1. Average frequency of alarms for sea areas per vessel.

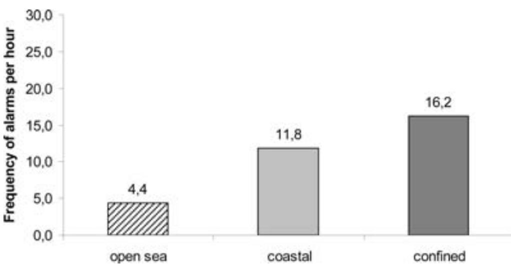

Figure 2. Average frequency of alarms for sea areas for all six vessels.

the vessel is sailing. Figure 1 shows the average frequency of alarms per hour for the three sea areas for each vessel investigated.

Except for Ferry 2, on all vessels considerably more alarms were recorded in coastal and confined conditions than in open sea areas. Altogether the analyses indicate a correlation between the traffic characteristics of the specific sea areas and the alarm occurrence.

This hypothesis is further confirmed when analyzing the average frequency for all six vessels (Fig. 2). Most alarms were recorded in confined and coastal waters. The occurrence of alarms at open sea was approximately four times lower than in confined waters.

3.3 *Dependencies on equipment*

Figure 3 depicts the distribution of alarms dependent on the device on which they occurred for the six vessels.

The vast majority of alarms was recorded at the radar device. Only on Container vessel 3 the percentage of radar alarms was lower than the amount of alarms that occurred at the ECDIS. This is due to the fact that on this vessel throughout the voyage AIS information was not integrated in the radar. Altogether the ECDIS aggregates the second highest percentage of the registered alarms.

The ECDIS was the only system besides the radar for which on each of the vessels alarms were recorded. Alarms on other devices were not appearing on all vessels, in some cases only on one vessel. These alarms

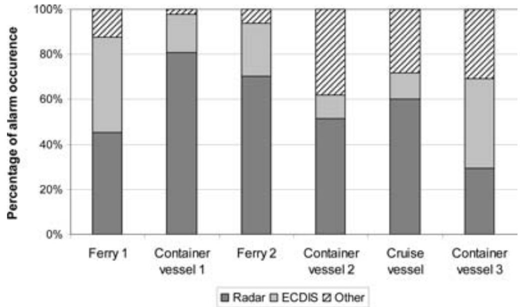

Figure 3. Distribution of alarms dependent on equipment per vessel.

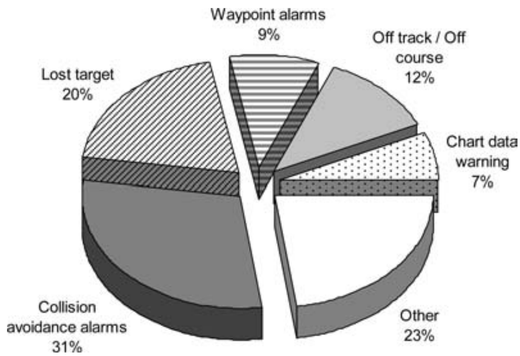

Figure 4. Average percentage of alarm categories for all six vessels.

reflected specific circumstances on the concerning vessel. On Container vessel 2 for example many alarms were registered on the GNSS and the gyro monitoring system, caused by the loss of the differential signal at the GNSS device.

3.4 *Dependencies on alarm category*

The distribution of the five alarm categories registered most often is shown in Figure 4.

For the purpose of the analysis the percentages for off track and off course alarms were summed up into one category. The category "collision avoidance alarms" includes the values for CPA/TCPA and Bow Crossing alarms. Aggregated into the category "waypoint alarms" are the alarms: early course change indication, actual course change indication and wheel over point. Alarm types summed up under the category "other" partly took percentages of up to 17% on one vessel but were registered only on that vessel – as for example DGPS failures on Container vessel 2.

For all vessels investigated the majorities of alarms are collision avoidance alarms and lost target alarms (51%).

CPA/TCPA as well as lost target alarms were predominantly triggered by AIS information, on average 72% of the CPA/TCPA alarms and 57% of the lost target alarms. (This percentage could have been even higher, if the bridge team of Container vessel 3 had not chosen a radar setting without integration of AIS information, which caused that all CPA/TCPA and lost target alarms were initiated by radar information.)

These results were expected due to the technical configuration and the use of the automatic alarm functions. For AIS, according to IMO regulations, the same limit values have to be applied as for tracked radar targets and the option for CPA/TCPA calculation was switched on to sleeping AIS targets by default. On two ships it was observed that CPA/TCPA and lost target alarms included targets that lay in the harbor basin behind land masses.

3.5 *Interview results*

During the field studies on board 13 mariners were interviewed. All of them were male with an average age of 36. Their average overall experience as mariner was 14 years, their average experience as an officer 9.5 years. The current position of the interviewees varied from master to third officer – most of the mariners were first or second officer.

Generally officers and masters feel that there are too many alarms occurring only for informative reasons on the bridge or can not be solved by the officer on the watch, for example "VDR record fault" or "window wiper oil low". Half of the mariners think that especially in certain situations for example the approach to a harbor such alarms are a major problem as they are distracting.

Mariners often reported alarms making annoying, loud and long lasting sounds, for example alarms from the navigation lights, echo sounder or gyro compass. Others pointed out that the acoustic presentation of an alarm often doesn't reflect its relevance. To identify the priority and the source of an alarm is seen as a general problem.

The majority favors to have the possibility to switch of the audible announcement of alarms in certain situations. Some mariners say that this concerns especially noisy alarms that are seen as less important. Others are referring to situations in which there is a lot of traffic, instruments are closely monitored and alarms are expected. However it is stated by some mariners that alarms for safety reasons, like fire alarms or engine shut down alarms, should always be audible.

Eighty percent think that a centralized alarm display for the centralized presentation of all alarms would support them with their tasks on the bridge. The vast majority feels that it would be a great benefit not to have to "run around the bridge" anymore trying to find out from which equipment an alarm comes from. Further expectations regarding a central alarm management display include a prioritization of alarms and the possibility to acknowledge or at least silence the alarms there. Some mariners worry that safety related alarms will not be immediately identified at a central alarm display for all alarms.

False alarms are seen as a problem. According to mariners especially distress alarms are often false alarms caused by users that send a message by mistake (without identification or position). Another problem are distress alarms from areas which are not of interest for the actual navigation situation.

Regarding the handling of alarms from the engine room presented e.g. on extension control panels on the bridge the statements differed. On some vessels the engine room is manned all or nearly all the time and alarms from the engine room are presented only for informative reasons without giving an audible announcement. On those vessels no difficulties with engine alarms are experienced. On other vessels alarms from the engine room give a sound on the bridge that stops, when the alarm is acknowledged in the engine room. On the bridge these alarms can not be acknowledged. It is only possible to silence the audible alarm. The tone is retriggered, when a new alarm occurs. This can lead to a distraction of the navigator, whose attention gets attracted by the sound again and again. Some mariners feel that those engine alarms are annoying.

4 DISCUSSION OF RESULTS

The field studies indicate a lack of a harmonized alarm management. The majorities of alarms recorded were collision avoidance and lost target alarms occurring on the radar, being triggered by AIS information. The peak values of alarms per hour were observed in confined waters. Under conditions of high traffic density, as for example at harbor entrances, alarms were often experienced as superfluous. However alarm thresholds were rarely adjusted. Instead the audible alarm announcement on the radar often was switched off in confined conditions. On some vessels the bridge teams suppressed collision avoidance alarms during departure and arrival by setting the alarm thresholds to a minimum. Altogether it can be concluded that especially in confined waters as harbor approaches where many AIS targets appear the navigators are overloaded with alarms.

The results showed further, that difficulties are related to the audible presentation of alarms and the necessary acknowledgement on various panels on the bridge, to the lack of indication of any priority of the alarms, to the lack of a consistent alarm acknowledgment concept and to difficulties in differentiating the audible alarm signals.

4.1 *Generic approach for reduction of CPA/TCPA alarms*

As collision warnings were found a major part of all alarms on the bridge the situation regarding high number of alarms may possibly be improved by enhanced triggering of these type of alarm.

One reason for the high amount of collision avoidance and lost target alarms in confined waters is to be seen in the technical configuration of AIS and the integration of sleeping AIS targets for the presentation of collision avoidance and lost target alarms. According to the new display and the new radar standards (IMO 2004a, IMO 2004b), future radar systems with AIS integration will allow the selective acquisition of AIS targets for collision avoidance alarms and more flexibility for the presentation of lost target alarms. That way future radar system will have the capability to reduce the number of alarms. However, further studies are needed, to investigate if this really will solve the problem.

Further reasons for the high amount of alarms in confined waters are on the one hand the missing of recommendations for thresholds to be used for CPA and Bow Crossing limits taking into account relevant situation parameters and on the other hand the missing possibilities to adjust the alarm initiation in an appropriate way beyond range and time to confined waters, where closer passing of vessels are to be expected.

One concept for the improvement of collision warnings has already been described earlier by Baldauf (2004). It bases on the definition of situation dependent thresholds, which take into account the type of encounter situation, the sea area and the visibility conditions. Core element of this approach is a risk model for situation assessment defining the three types of encounters – meeting, overtaking and crossing courses – and considering the two conditions of good and restricted visibility as laid down in the International Rules for Preventing Collisions at Sea. To reduce the number of collision warnings the situation-dependent thresholds for CPA and TCPA can be applied by an algorithm for self-adaptation of these values to the prevailing circumstances of a certain situation and the maneuvering characteristics of the involved ships. According to first preliminary tests using a set of determined initial situation-dependent CPA values to recorded open sea scenarios a significant reduction of occurring collision warnings was reached (Baldauf et al. 2008).

5 PERFORMANCE STANDARDS FOR BRIDGE ALERT MANAGEMENT

A lot of deficiencies observed in the field studies will be solved for INS installed after January 1st 2011 for which an alarm management, according to the revised INS performance standards (IMO 2007), is mandatory.

This alarm management system for navigational alarms aims to harmonize the operation, handling, distribution and presentation of alarms. To improve the operator's situation awareness and his ability to take effective action a set of priorities is introduced based on urgency of the required response. A new philosophy is followed for the prioritization and categorization of alarms. Alert (alert management) is defined as umbrella term for the indication of any abnormal situation with three different priorities of alerts (IMO 2007, Motz & Baldauf 2007):

- alarm (highest priority) – conditions requiring immediate attention and action by the bridge team to avoid any kind of hazardous situation and to maintain the safe navigation of the ship;
- warning – conditions or situations which require immediate attention for precautionary reasons, to make the bridge team aware of conditions which are not immediately hazardous, but may become so; and
- caution – awareness of condition which does not warrant an alarm or warning condition, but still requires attention out of the ordinary consideration of the situation or of given information.

The three priorities are indicated visually and acoustically in different ways. Whereas alarms initiate an audible signal and a flashing visual indication until acknowledgement, warnings are presented with a momentarily audible signal and a flashing visual indication until acknowledgment. After acknowledgment both alarms and warnings are presented with a steady visual indication. Cautions are only indicated by a steady visual indication and don't have to be acknowledged. It is also possible to temporarily silence alarms.

To ensure a consistent presentation of alerts and to reduce the presentation of high priority alerts within the INS, alerts released by navigational functions, sensors, sources are presented as far as practicable, after evaluation with the system knowledge of the INS, e.g., provided by the integrity monitoring. This means that the priority of an alert will be assigned and presented consistently for all parts of the INS, and can be reduced for the alert in case of sufficient redundancy. E.g., in case of a failure of one of three position sensors only a caution may be released for the INS as still a reliable system position can be presented.

Additionally the INS performance standards include requirements for a central alert management human machine interface (HMI) for navigation related alerts (IMO 2007). Such a centralized presentation is part of an INS to support the bridge team in the immediate identification of any abnormal situation, including the source and reason for the abnormal situation and information for decision support for the necessary actions.

The central alert management HMI has to fulfill three major functions: indicating and identifying alerts, allowing to temporarily silence all alarms and allowing the acknowledgement of all alarms and warnings for which no additional graphical information is necessary as decision support for the evaluation of the alert related condition.

The alert management system within INS was developed with the intention to be extendable to an alert management concept for the whole bridge. The findings of the field studies showed that the aspects which were contributing to the development of the INS alert management are also to be applied to the alert management system for all alerts on the bridge.

Accordingly the performance standards for Bridge Alert Management, which is currently developed at IMO, picks up most of the ideas of the INS alert management. In doing so the performance standards consists of two major parts: A general module aiming to harmonize the presentation and handling of all alerts on the bridge (equivalent to the prioritization introduced within INS) and additionally requirements for a central alert management HMI.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

5.2 Comparison of traditional and integrated bridge design with SAGAT

F. Motz, E. Dalinger, H. Widdel & S. Höckel
Research Institute for Communication, Information Processing and Ergonomics, Wachtberg, Germany

S. MacKinnon
Memorial University of Newfoundland, St. John's, Canada

ABSTRACT: Modular Integrated Navigation Systems (INS) according to the revised IMO performance standards on INS combine and integrate the validated information of different sensors and functions and allow the presentation on the various displays according to the tasks. The aim of the investigations discussed within this paper was to assess the advantages of an INS design compared to a traditional bridge layout with respect to the execution of collision avoidance and route monitoring tasks. The Situation Awareness Global Assessment Technique (SAGAT) approach was applied to assess Situation Awareness (SA) during these operations while bridge design and out of window visibility were manipulated. Additionally, workload was measured by NASA-TLX with its six subscales. The experiment was conducted in a full immersive simulation environment with 26 experienced mariners. The results indicate that SA is significantly higher with the INS bridge design in the reduced visibility condition compared to the traditional bridge design. Also, tendencies were found that workload and subdimensions are influenced by bridge design and visibility conditions.

1 INTRODUCTION

Modern ship bridges are highly-automated man-machine systems. Safety and efficiency of the ship operations are dependent upon the ability of a watch-keeper to perceive, interpret, and make decisions upon information acquired from the surrounding environment. In the last years a strong increase of modern information systems on ship bridges could be observed. Simple displays and control systems were supplemented or replaced by complex computer-based information systems. In order to support the mariner effectively onboard, a task- and situation-dependent representation of the information is a compelling need. Modular Integrated Navigation Systems (INS) according to the revised IMO performance standards on INS (IMO 2007) combine and integrate the validated information of different sensors and functions and allow the presentation on the various displays according to the tasks.

The aim of the investigations discussed within this paper was to assess the advantages of an INS design compared to a traditional bridge layout with respect to the execution of collision avoidance and route monitoring tasks. The Situation Awareness Global Assessment Technique (SAGAT) (Endsley 2000) approach was applied to assess Situation Awareness (SA) during these operations while bridge design and out of window visibility were manipulated. The method to assess the SA of watchkeeping officers on ship bridges was developed based on previous studies (Motz et al. 2008).

The experiment was carried out in the full mission bridge simulator of the Centre for Marine Simulation (CMS) of Memorial University of Newfoundland, St. John's, Canada. The experimental trials were conducted in a full bridge environment and carried out with four scenarios, to investigate the influence of bridge design and outside visibility on the SA of watchkeeping officers. The subjects were tasked to navigate a vessel in scenarios with varying traffic situations. In the trials a watch hand over was simulated so that after the first 10 minutes of monitoring and evaluating the traffic situation the subject assumed full control of the vessel.

2 SIMULATOR AND BRIDGE DESIGN

The experiment was carried out in a 6 degree of freedom motion base, full mission ships bridge simulator (see Fig. 1). The simulator was manufactured by Kongsberg Maritime Ship System. All trials were conducted under a repeated motion profile. In the experiment two bridge configurations were compared: a traditional layout employing the existing navigational equipment and an INS design. The major difference between the two designs is the factor of integration of the collision avoidance and navigation information, including route monitoring and planning. The

Figure 1. Full mission ships bridge simulator.

Table 1. Samples of SA questions.

Level	Question
Perception	What is the current position of your vessel? What is the course of the blue highlighted vessel?
Comprehension	What is the distance to the next waypoint? What is the direction of the course change of the highlighted vessel?
Projection	What is the CPA of the blue highlighted vessel? In how many minutes will you reach the pilot station?

arrangement, location and design of the equipment of both configurations were identical.

The following set up was used as traditional configuration:

- radar with facilities to display tracked radar targets
- electronic Charting Display and Information System (ECDIS) with route information
- minimum keyboard Display (MKD) to display AIS target information
- depth sounding information
- heading information
- speed information
- VHF communication (Navtex, VHF DSC)
- propulsion status displays
- steering and engine control
- steering status displays
- alarm information presented on the individual equipment
- chart table with paper charts.

For the INS configuration the information of the various navigational systems were integrated and combined in the displays on the bridge:

- collision avoidance display: radar with tracked radar targets and AIS targets, possibility to underlay ENC chart information
- route monitoring display: ECDIS with active route and AIS targets
- conning display: position, propulsion information, rate of turn, relative wind speed and direction, engine alarm status, rudder indicator, gyro repeater and speed
- minimum keyboard Display (MKD) to display AIS target information
- speed information
- VHF communication (Navtex, VHF DSC)
- propulsion status displays
- steering and engine control
- steering status displays
- alarm information presented on the individual equipment
- chart table with paper charts.

3 SAGAT

Situation Awareness is generally understood as "knowing what is going around you". Within the research community the definition of Endsley (1995) has been widely accepted in various domains. In a cognition-oriented approach, the model considers three levels and includes:

- perception of elements,
- comprehension of the meaning of the elements and the situation, and the
- projection of the status of the elements and the situation into the immediate future.

According to this model, decision making and performance is influenced by SA.

The Situation Awareness Global Assessment Technique (SAGAT) is probably one of the most well known SA measuring techniques (Endsley 2000). It provides an objective explicit measure of SA by directly comparing the operator's SA to an operational "scenario". With this technique, a simulation is frozen at a specific time, the system displays are blanked while the operator quickly has to answer questions concerning the scenario. Temporary freezes in the simulation must be of a short duration to minimise intrusiveness and memory decay. To get an accurate measure of the operator's SA the SAGAT probes must cover all three levels of SA and must be reflective of a wide range of the SA requirements. These are delineated through a goal-directed task analysis.

The method originally was developed for the aviation domain (e.g. Endsley 1990, Strater & Endsley 2000) and has been applied in identical or modified forms in other domains. Presently, it was adapted to the marine domain (Motz et al. 2008). A sample of SAGAT probes for marine application is shown in Table 1.

SAGAT can be a useful tool to evaluate system design. SAGAT can provide a form of diagnostic information that indicates how a technology's design could improve or weaken an operator's SA when compared to a baseline technology. This information can then be used to refine design concepts. For the ergonomic evaluation of the task- and situation orientated presentation of navigational information on INS it was considered to use the concept of situation awareness measured with SAGAT.

Questions related to *perception of elements* (level 1) refer to the status of own ship as well as dynamics of relevant objects in the environment. A mariner has to possess correct information of own ship (position, route, course etc.) as well as correct information about targets (speed, distance etc.).

Questions related to *comprehension of meaning* (level 2) go beyond simply being aware of the elements that are presented. An understanding of the significance of those elements in light of mariner's goals is included. For example, a mariner must quickly determine those targets which pose a threat and eventually demand operator action to mediate a threat or obstacle.

Questions related to *projection of the near future* (level 3) refer to future actions of the elements in the environment. This is achieved through knowledge of the status and dynamic of the elements and a comprehension of the situation.

4 EXPERIMENT

4.1 *Subjects*

26 experienced mariners (masters, navigational officers, pilots) participated in the trials. The requirements for subject recruitment were:

- at least half a year experience as officer of the watch (OOW)
- the mariners must have navigated a vessel in the last four years
- or working actively as navigational simulator instructors.

4.2 *Hypotheses*

It was hypothesized that navigating with INS bridge design leads to higher SA scores than navigating with traditional bridge design. This effect might be more distinctive under difficult conditions like reduced outside view when fog prevails than under good view. In the case of bad navigation conditions also mental workload may be increased.

4.3 *Experimental design*

A 2×2 factorial design with two within-subject factors was used. The first within-subject factor *bridge design* varied on the two levels:

- traditional configuration
- INS configuration.

The second within-subject factor *visibility* varied on the two levels:

- good visibility
- reduced visibility (fog).

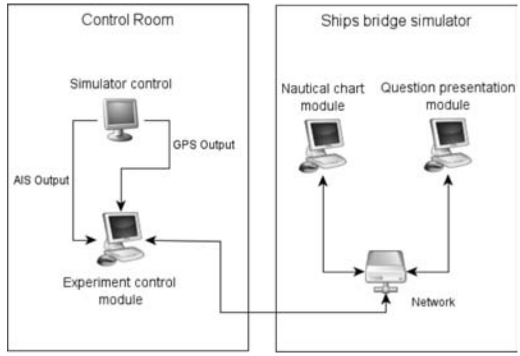

Figure 2. Controlling components of experiment.

Dependent variables were SA and NASA-TLX scores (Hart & Staveland 1988).

A 2×2 repeated measures ANOVA (Analysis of Variance) model with the within subject factors *bridge design* and *visibility* were employed to analyse these data. As dependent variables the relative frequency of correct answers representing the SA score were analyzed. For workload the NASA-TLX scores were used. All statistical interpretations were considered at the 5% level of significance.

4.4 *Experimental control*

The experiment was carried out in the ships bridge simulator with the two bridge designs described in Section 2.

To control the presentation of SA questions on the bridge, to log the answers of the subjects and to monitor the vessels involved in a scenario an experimental controlling program was developed by Research Institute for Communication, Information Processing and Ergonomics. The program consists of the question presentation module, the nautical chart module presenting the graphical information for the SA questions and the experimental control module (see Fig. 2). The three different modules were located on different computers in the network. Whereas the nautical chart module and the question presentation module were installed on the navigational bridge of the simulator, the experimental control module runs on a PC in the simulator control room.

The experimental control module fulfilled the three main tasks *processing of simulator output*, *target control* and *control of SA questioning.*

The experimental control module read and processed the data of own ship's GPS output signal and the AIS signals of the other vessels provided to the navigational equipment (e.g., the radar, ECDIS or the MKD) on the bridge. This allowed the SA questions to be posed using real-time data. Therefore, the software offered the possibility to show during the simulation the movement of own ships and the other vessels on a chart background and to offer suggestions to change the course or speed of the vessels in case of course or speed alterations of the own ship in order to present the SA questions in similar traffic situations for all participants.

4.5 *Presentation of SA questions on the bridge*

When the scenarios were "frozen" to present the subjects the SA questions, the simulation was suspended, all task relevant information was removed from the navigational equipment on the bridge and the outside view was blanked. The SA questions were then administered on two displays on the bridge. Whereas on one of the displays the questions were presented, on the other display additional graphical information for certain questions were displayed (see Fig. 2).

This offered the four techniques to ask the SA questions, depending on the topic, complexity and the easiest way to present and to answer the questions:

- *numeric open-end questions:* Questions appeared on the question display as numeric open-end questions, e.g., *what is your heading after the next waypoint*. No graphical information was presented on the graphical information display. To answer the questions the subjects had to type in the right answer and then to click on the continue button to proceed with the next question.
- *open-end questions with graphical answer:* The question after the position of the vessel appeared on the question display as open-end question (instruction) and had to be answered on the graphical information display by clicking on the chart background.
- *numeric open-end questions with additional graphical information:* Questions appeared on the question display as open-end questions with additional information presented on the chart of the graphical information display, e.g., the target involved in the question. To answer the questions the subjects had to type in the right answer and then click on the continue button to proceed with the next question.
- *multiple choice questions with additional graphical information*: Questions appeared on the question display as multiple choice questions and on the graphical information display question related information was presented on the chart background. To answer the questions the subjects had to select the right answer and then to click on the continue button to proceed with the next question.

A preliminary question-pool of about 70 questions had been developed referring to the navigation of the vessel focusing on route monitoring and collision avoidance. The questions were evaluated in pre-tests which had the aim of selecting the most relevant questions, of testing the content and understandability, and to reduce the number of questions resulting in a set of 16 questions on three levels (see Table 1 for examples).

4.6 *Traffic scenarios*

The SAGAT approach required the development of realistic scenarios based on specific criteria, e.g., course change of own ship, navigational hazards,

Figure 3. Singapore scenario at the first freezing.

traffic density, and "interest/danger" of targets. The criteria for traffic density and "interest" of targets are:

- total number of targets – 20
- number of targets within a 3 NM range – 10
- number of targets within a 3 NM range: close quarter targets (CPA: 0.5–1.5 NM); with a collision course, overtaking own ship or overtaken by own ship – 5
- number of targets, which cause a reaction because of collision course – 1.

On the basis of these criteria four traffic scenarios with duration of 21.5–25 minutes were developed, as well as one familiarization/habituation scenario. To ensure that the previous knowledge of traffic and of the sea area doesn't influence the results (i.e. a learning effect was controlled for), the scenarios represent different traffic situations for the Juan de Fuca Strait/Strait of Georgia (familiarization scenario), English Channel and Singapore. Figure 3 shows one Singapore scenario at the time of the first freezing. In the pre-trials the traffic scenarios were evaluated in respect to realism, relevance and complexity.

4.7 *Experimental procedure*

The experimental procedure had five steps.

In the first step the experiment was introduced to the subjects in a briefing outside the simulator. Subjects had to complete a personal data sheet, which was used to gather data like current occupation, years of experience as mariner, and age, and the intention of the experiment and general description of experimental set up were described to the subjects.

In the second step subjects were familiarized in the simulator with the experimental procedure and the bridge equipment. The INS design and the traditional layout were explained in detail and the procedure with the presentation of scenarios and the following interruptions for SA questioning were explained.

In the third step familiarization trials were conducted, one familiarization trial for each bridge layout. The purpose was to familiarize the subject with the navigation of the vessel with the different bridge layouts, with the experimental procedure of the freezings and with the different types of SA questions. The familiarization trials were carried out without motion and with good visibility for all trials.

In the next step the four scenarios were presented to the subject in a randomized order. The task of the subject was to navigate a vessel in traffic situations of varying density with either good or reduced visibility. In the trials a watch hand over was simulated so that the first 10 minutes of each scenario the subject monitored and evaluated the traffic situation. An instructor was fulfilling the role of the officer of the watch for the first 10 minutes. After the hand over, the subject was in full control of the vessel. An instructor remained on the bridge and acted as both the helmsman and the master. Thus, as the helmsman, the instructor performed any changes in speed and course and as master, to deny inappropriate decisions of the subject that might disrupt the whole experiment.

During each scenario there happened four freezings in which the outside view and the displays were blanked and the SA questions were asked. The first freezing was conducted at the watch hand over and the last at the end of the scenario. Same questions were asked for all treatments, 16 questions per scenario divided into 4 groups of 4 questions.

At the end of each scenario the NASA-TLX rating scale was completed. Following the collection of all four scenarios the NASA-TLX rating paired comparisons questionnaire were completed.

The duration of a simulation trial (4 scenarios and habituation) per subject was between 190 to 220 minutes, depending on the time each subject needed to become familiarize with the bridge equipment. The trials were carried out with motion.

After the trials a SAGAT debriefing questionnaire and a INS questionnaire to evaluate certain aspects of an INS layout were administered to the subjects in a separate room.

5 RESULTS

5.1 *Main results*

The central questions of the experiment were focused on the impact of the independent variables, *bridge design* and *visibility*, on situation awareness. The means of frequencies of correctly answered SA questions are shown in Figure 4. The results of the ANOVA for the within subject factors *bridge design* and *visibility* show a significant main effect for the factor *bridge design* ($F_{1,25} = 4.88$, $p < 0.05$) and a significant interaction effect between *bridge design* and *visibility* ($F_{1,25} = 6.94$, $p < 0.05$). No significant effect for the factor *visibility* ($F_{1,25} = 0.94$, $p > 0.3$) could be found.

The analysis of variance executed for the *overall workload*, defined by the total score of NASA-TLX, does not result in significant differences for the two main effects *visibility* ($F_{1,25} = 3.57$, $p = 0.07$) and *bridge design* ($F_{1,25} = 1.01$, $p = 0.32$) or for the interaction ($F_{1,25} = 0.13$, $p = 0.72$). But a strong tendency can be seen that the INS produces less workload than a traditionally designed bridge, and reduced visibility is responsible for higher workload. Although, tendencies were found for the subscales *performance* and *effort* favoring the INS bridge design especially under the condition of reduced visibility.

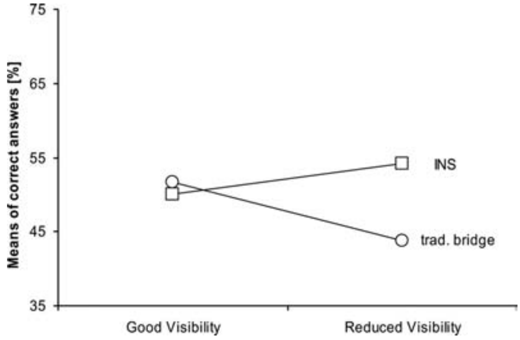

Figure 4. Dependency of SA from bridge design and visibility.

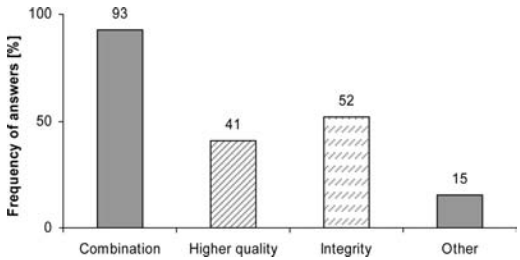

Figure 5. Means of frequency for the added value of an INS bridge.

Results from the INS questionnaire support the empirical data collected in this study. In general, the majority of the subjects (93%) preferred the INS bridge design compared to traditional design. The participants who preferred the traditional bridge gave as reasons that they are more used to the traditional design and that the INS design provides too much information. As added value of an INS almost all participants chose the answer “the combination of information” (see Fig. 5). Half of the respondents selected “the integrity of data” (meaning the possibility to compare automatically data from independent sources). Less often selected is “the higher quality of information”.

5.2 *Post-hoc analysis*

The definition of SA specifies a hierarchical structure with three levels (see Section 3). Questions for the first level are preconditions for answering questions on level 2 and 3. Following this hierarchical organization leads to the assumption that questions of level 1 are answered correctly more often than questions of the higher levels.

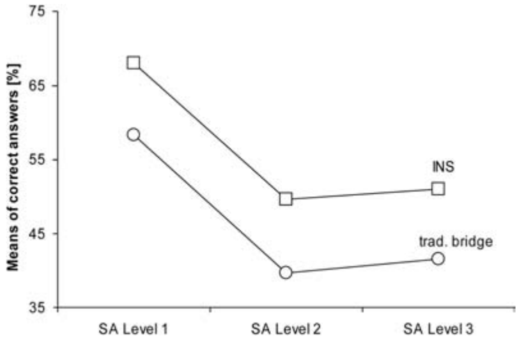

Figure 6. Dependency of SA from bridge design on the three SA levels.

In the post-hoc analysis the factor *level of SA* was included. A 2 × 2 × 3 ANOVA with the factors *bridge design*, *visibility* and *level of SA* as within subject factors was performed to test the assumption which was justified by a significant main effect of the factor *level of SA* ($F_{2,50} = 43.47$, $p < 0.001$).

A pairwise comparisons with Bonferroni correction of the three SA level scores show a significant higher score for level 1 compared to level 2 and level 3, but no difference between the latter two. In Figure 6 the means of frequencies of correct answers for the 3 levels of SA are shown for condition *reduced visibility*.

SA level 1 (perception) had a greater score than SA levels 2 and 3 (comprehension and projection), suggesting that the application of SAGAT in this maritime-related research was a valid approach to assess global SA.

6 CONCLUSIONS

The results indicate that bridge design has a significant impact on the degree of situation awareness, as hypothesized. SA is significantly higher with the INS bridge design in the reduced visibility condition compared to the traditional bridge design. In good visibility the SA is similar with both bridge designs. Mariners have to rely more on information systems when navigating in reduced visibility conditions. It can be hypothesized that not only reduced visibility but detrimental navigational conditions, in general, may reduce SA when navigating with traditionally designed bridges but not with INS. These considerations also apply to workload in the sense that stress inducing work conditions can influence total workload and subdimensions of NASA-TLX like performance and effort when using traditional bridge design.

Further experiments are required comprising more difficult navigation surroundings, e.g., higher traffic density, more challenging navigation tasks, high stress inducing work environment, to confirm and sharpen these experimental findings.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

5.3 The problem of "infant mortality" failures of integrated navigation systems

S. Ahvenjärvi
Satakunta University of Applied Sciences, Rauma, Finland

ABSTRACT: This paper deals with the problem of high failure rate often experienced on ships that are equipped with a new integrated navigation system. These "infant mortality" failures of the navigation system can form a significant risk to the safety of the ship, as the history has shown. Some accidents caused by this type of failures are briefly discussed. The paper highlights some factors that promote this problem. One of the most important factors is the low degree of standardisation of the bridge systems. Another factor is the incompleteness of the self diagnostics of a new system. The role of the self diagnostics is crucial in coping with failures, because the redundancy of the navigation systems is typically based on manual activation of the back-up device or function. The necessary corrective action by the user can be delayed too much if the self diagnostics of the system is not able to detect the failure. Proper testing of the new system during the harbour trials and the sea trials as well as utilisation of efficient failure analyses techniques is important for reducing the safety risk caused by the infant mortality failures. In the end of the paper, some practical experiences of using FMECA and HAZOP analysis in the development of the integrated navigation system of a large cruise vessel are presented.

1 INTRODUCTION

The bathtub curve is a widely used figure to describe the failure rate of a product during its lifetime. The curve consists of three phases: the "infant mortality" period, the "normal operating" period and the "wear out" period, see Figure 1. This kind of failure curve is typical for complicated technical systems, such as cars, consumer electronics and computer hardware, for instance. The high failure rate in the beginning of the lifetime of a complicated automation system is mainly explained by the existence of latent software errors. The frequency of software-based failures is high in the beginning, but it decreases throughout the lifetime of the software product, as illustrated by the yellow line Figure 1. The explanation is that a piece of software does not wear out or fail, but all failures or malfunctions are caused by latent software errors, or bugs. There are more bugs in a new software product, but as the product gets older, the latent errors are gradually being found and corrected. Provided that the software updates are made correctly, i.e. new errors are not created when software bugs are being eliminated, the failure rate steadily decreases.

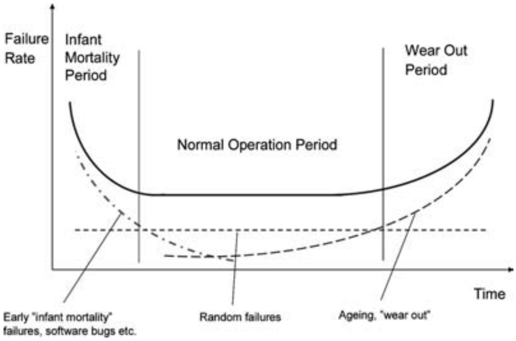

Figure 1. The bathtub curve.

It can be assumed that the failure rate curve of an Integrated Navigation System (INS) of a ship has also the shape of a bathtub during its lifetime. There is some evidence about higher failure rates of new INSs, although extensive statistical data seems not be available about this matter. After 1994 on Finnish waters, there have been several groundings caused by a failure or a malfunction of the navigation and steering system of the ship [1]. Almost all the systems involved were new and the failures fell in the category of infant mortality failures.

There are factors that seem to promote the infant mortality problem of INSs of ships. The first one is the lack of standardisation. The INSs of ships are typically tailor-made. The risk for unknown failure modes and unknown software errors in such systems is higher than in standardised, mature systems. Gradually, as the unknown failure modes are found and eliminated, the failure rate decreases. When the ship and its navigation equipment have passed the infant mortality period, the probability of an accident due to unknown dangerous faults decreases.

2 SOME ACCIDENT CASES

A fault of a critical component of the navigation system of the ship was the initial cause of the following five real accident cases: Grounding of the passenger ferry M/S Silja Europa in the Swedish archipelago close to Stockholm in January 1995, grounding of the tanker ship M/T Natura in front of Sköldvik in October 1998, grounding of the ro-ro passenger ferry M/S Finnfellow in Åland in April 2000 and the grounding of the passenger ferry M/S Isabella in Åland in December 2001 and the grounding of M/S Royal Majesty close to the east coast of the USA in June 1995 (OTK, 1995; NTSB, 1997; OTK, 1998, 2000 and 2001).

A remarkable feature about these five cases is that the failed equipment was rather new. M/S Silja Europa was constructed less than two years before the accident. M/S Royal Majesty was constructed three years prior to the accident. M/T Natura was constructed five years prior to the accident. The compass system of M/S Finnfellow was upgraded only 13 months before the accident. The INS of M/S Isabella had been renewed around six years prior to the accident. So the average age of the failed equipment was around 3,5 years, which is not much when it is compared with the typical lifetime of a ship, 25 to 30 years. So the critical faults of the five accident cases were not caused by ageing or "wear out", but by the "infant mortality" of the equipment. This applies even to the Royal Majesty case: Although the original fault, i.e. separation of the signal cable from the GPS antenna, can be considered a random failure, the other factors fall into the "infant mortality" class.

3 FACTORS THAT PROMOTE THE PROBLEM OF "INFANT MORTALITY" FAILURES

A critical fault in the INS of a ship represents a high safety risk especially in restricted waters and in areas with high traffic density. The south-west coast of Finland, for instance, is surrounded by a wide archipelago area. Navigation on these waters is very demanding. In Figure 2, there is a sample from the sea chart of the archipelago area close to the city of Turku. The fairways are winding with the minimum fairway breadth only ca. 150 metres.

In this area, the available time margin to avoid a grounding after a critical failure can be only a few seconds. For instance, the grounding of the ro-ro passenger ship M/S Finnfellow in April 2000 took place only 85 seconds after a fatal gyro compass failure. Even though the deck officers noticed the abnormal turning of the ship 30 seconds after the failure, it was too late to avoid the grounding (OTK, 2000). Figure 3 shows the position of the ship only 90 seconds after the failure!

The risk of an accident caused by unknown failure modes is high when recovery of the failure is dependent on proper corrective action of the user. This is still the case in most of the new INS installations. The user has to activate the back-up device or function if the active unit fails. In order to be able to do so, the user has to be aware of the operational status and condition of the system and its critical components.

Figure 2. A sample of the archipelago of the south-west coast of Finland.

Figure 3. Position of M/S Finnfellow 90 seconds after the critical compass failure (OTK, 2000).

The self diagnostics of the system is crucial for the user to maintain the situation awareness and to be able to react quickly and correctly to failures. It can be seen quite easily from the past accidents, that the user of the INS can have serious difficulties in registering a failure in the system, if the system does not give any alarm about the situation. The failure detection delay can in some cases be extremely long, as was in the M/S Royal Majesty case.

The user's dependency on the self diagnostics makes unknown "infant mortality" failure modes especially dangerous, because they have not been anticipated by the software engineer who designed the self diagnostics of the system. In other words, an unknown "infant mortality" failure will probably not cause an immediate alarm. It is interesting that actually the designers of the system make a double error when they do not recognise a dangerous failure mode: no measures will be taken to eliminate the failure mode in concern AND it will not be ensured that the self diagnostics of the system is able to detect the failure.

Poor or incomplete self diagnostics is a typical problem of new technical systems. Development of proper self diagnostics is expensive and it may be one of the last things to be developed to a new product. The weaknesses of the self diagnostics may become apparent to the user and to the manufacturer years after the commissioning of the system. Nancy Leveson states that "the carefulness in designing and testing is too often directed to the normal operation of the system, while the unexpected and erroneous states get much less attention" (Leveson 1995, p. 400). The development of this important area of system safety need new regulations about self diagnostics, for instance demonstration of the completeness of the self diagnostics as a part of the type approval procedures.

The disability of the system to detect failures and malfunctions, i.e. the deficient self diagnostics, is a serious weakness of new INSs. Increasing complexity of the systems and the relatively short lifetime of product generations seem to promote this weakness. Another factor is the lack of standardisation. In order to make the detection of abnormalities quick and reliable, there has to be much knowledge about the structure and operation of the individual parts and devices of the system, and a lot of practical knowledge about the use and the operation of the system. Fulfilment of these requirements is difficult without better standardisation of INS systems. It is a well known fact that the INSs are too often tailor-made entities. Even sisterships are too often equipped with different INS setups. However, in order to reduce the safety risk caused by "infant mortality" failures, that kind of tailoring should be stopped. From this point of view, it would be ideal if there were only very few alternative system setups available on the market. Moreover, the INS manufacturers should make the lifetime of a product generation as long as possible. Unfortunately, due to the competition (obviously), the manufacturers tend to introduce new product generations more and more frequently. That is a wrong strategy for reducing the safety risk caused by "infant mortality" failures.

4 WHAT CAN WE DO ABOUT IT?

Alternative methods to reduce the safety risk caused by "infant mortality" failures of INSs would be

1. to increase the lifetime of INS product generations
2. to improve standardisation of INSs
3. to require better testing of new products from INS manufacturers, including the demonstration of completeness of the self diagnostics
4. to make the INSs more fault tolerant
5. to apply different failure analysis methods to new systems prior commissioning

The first method is difficult to accomplish. The competition on the market seems to force the manufacturers to introduce new innovative system generations every other year. As customers, are we happy about this situation? Would we prefer a fully tested, reliable INS in stead of a brand new system with all latest features – and with all those "infant mortality" problems? The customers must realise the importance of this matter and ask for reliability rather than for new architecture or new functions. Would it be a good idea to establish a www-based failure register for the INS products on the market. The database could be maintained by all users of the INSs. It could give the customers some idea about the reliability of different products on the market and hence make the reliability more important also for the manufacturers.

The second and the third method would require new regulations from the international shipping community. The new concept of e-navigation should be used for this purpose. Thorough failure mode testing and demonstration of the completeness of the self diagnostics should be included in the type approval test requirements. Introduction of new system generations would become more difficult, which would also support the increase of product lifetimes.

The fourth method would consist of automatic recovery functions in fault situations. This is the most powerful method to reduce the risk of accidents due to a single failure in the system – no matter if it was an "infant mortality" failure or something else. Automatic redundancy has been successfully applied in many areas of safety critical automation, such as dynamic positioning of offshore vessels and automatic flight management of modern passenger aircrafts.

The fifth method is already in use. The difficulty in making proper failure analysis for a new INS is that the manufacturer has got the best and the most important information about the system. It is well known that the all failure analysis methods, such as the Failure Mode, Effect and Criticality Analysis (FMECA), is very much dependent on the quality of the data about the technical structure and the software of the analysed system. In practise, the manufacturer is the only party that possesses this information and thus can make a good and comprehensive failure analysis for the product. The author of this paper has coordinated recently two failure analysis projects for large INS systems of passenger cruise ships (see Ahvenjärvi, 2005). These projects confirmed that the manufacturer of the system, indeed, plays the key role in analysis of a new product. It turned out that an FMECA made by the manufacturer(s) and commented by the shipyard/the owner of the ship, combined with a Hazard and Operability Analysis (HAZOP) can give useful results for reducing the risk of an accident due to unknown failure modes. The problem of these methods is that you can never know, if all failure modes – or even most of them – have been detected in the analysis. Actually it is unrealistic to assume that all possible failure modes have been found by using these techniques. Suokas et al. (1988) studied the validity of different methods of identifying accident contributors in process industry systems. The study showed relatively low validity figures for the FMEA, only 17% of contributors of hazards could be identified by applying FMEA. Other methods were not better than FMEA. Thus it can be assumed that even the combined use of FMECA and HAZOP would cover less than half of all potential failure modes, i.e. the other half of the “infant mortality” failures would remain unpredicted.

5 CONCLUSIONS

A brand new INS with updated architecture and a new software with the latest innovations is not necessarily the best choice for a ship, especially if it will be sailing in areas with narrow fairways or dense traffic. A new system suffers from the “infant mortality” failure phenomenon discussed in this paper. The problem is a combination of three factors: increased failure rate (due to hardware failures and software errors) in the beginning of the operational time of the system, unknown failure modes and incompleteness of the self diagnostics of the system. As the result, the user may lose the control of the situation, if a failure hits the system and it is not capable of giving an alarm about it. The risk of an accident is high if the time margin to make a corrective action is short. Several accidents have taken place due to this kind of “infant mortality” failure.

Obviously the most powerful methods to reduce the risk of this kind of accidents is to make the lifetime of product generations longer and by placing more strict requirements for testing of new systems before they can be taken into use. Standardisation would also be a useful way to limit the number of different types of INSs and hence to reduce the risk of unknown failure modes. These methods, however, require international cooperation and new regulations. Perhaps a web-based failure database could also be useful to encourage the system manufacturers to put a higher priority on reliability and safety than on introduction of new features and new design as frequently as possible. Risk evaluation techniques, such as FMECA and HAZOP can also be used to analyse potential failures of a new INS, but it should be realised that even a good analysis will cover only a fraction of all possible unknown failure modes.

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5.4 CRM-203 type Frequency Modulated Continuous Wave (FM CW) radar

S. Plata
Telecommunication Research Institute Ltd., Gdańsk, Poland

R. Wawruch
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: Paper presents description of the principle of work, structure and basic technical parameters of the Maritime Coastal Surveillance Frequency Modulated Continuous Wave (FMCW) Radar CRM-203 type constructed by Telecommunication Research Institute Ltd. in Gdañsk. Results of its tests in real conditions and comparison with pulse ship radars with scanners installed in the same place will be presented during the conference.

1 INTRODUCTION

The CRM-203 type Coastal Surveillance Radar is solid state Frequency Modulated Continuous Wave (FMCW) sensor with low transmission power. One of the most significant parameters of this coastal application is small targets detection possibility in heavy sea clutter conditions and high range resolution. The requirements perform FMCW technology, which is rapidly advancing recently. Fully solid-state transmitter design (due to the low radiated power) ensures excellent Mean Time Between Failure (MTBF) and practical without service continuous operation.

FMCW transmitter produces a constant amplitude linear frequency modulated signal. The principle of FMCW radar is presented on Figure 1.

Radar signal is transmitted, reflected by the surface of the target and then received after a delay time τ:

$$\tau = 2R / c \quad (1)$$

where: c = speed of light; and R = distance.

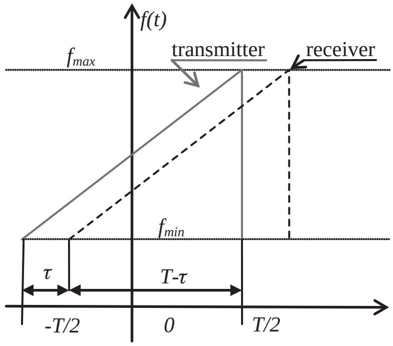

Figure 1. Principle of FMCW radar.

The difference between the transmitting and receiving frequency f_R is directly proportional to the distance and is used to further FFT processing (Wawruch & Stupak 2008):

$$f_R = 2R\Delta f / cT \quad (2)$$

where: Δf = frequency deviation; and T = modulation period.

Frequency Modulated Continuous Wave technology offers low probability of intercept feature because of the low peak power and frequency modulation.

2 RADAR GENERAL DESCRIPTION

The prime function of CRM-203 is detection and estimation of planar co-ordinates for sea surface targets and automated tracking the selected ones to perform the coastal surveillance tasks. The radar sensor gives a presentation of the current sea situation and calculates the future situation to accomplish the automated radar plotting aids.

Functional diagram of described radar is presented on Figure 2. Radar sensor basically includes the antennas integrated with FMCW transceiver, antennas motor drive and Signal Processing & Control Unit (SPCU) also including local interface and control circuitry. Each radar transceiver is controlled by the SPCU which is connected to the Operations Centre (OC).

The main functions performed by radar are:

– selection of the operative mode (local or remote); reception from the OC of all controls/ commands and selections needed for complete operation capability; in case of control line failure all the controls are automatically put in a default condition – in order to guarantee the antenna rotation, the radar

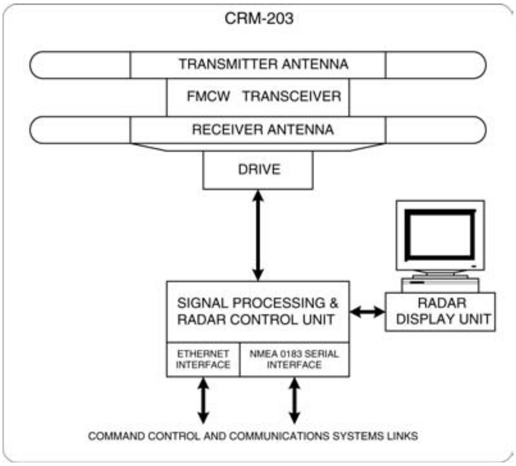

Figure 2. CRM-203 functional diagram.

emission and the automatic acquisition and tracking of targets;
- processing of the radar video; compression and transmission to the OC of the digitised video;
- automatic or on-demand acquisition of targets falling inside predefined automatic acquisition zones or acquired by the operator;
- automatic tracking of targets falling inside predefined automatic tracking areas; and
- transmission to the OC, once per antenna revolution, of status and alarms from the sensor (BITE), track data (position, speed/course) of targets under tracking.

3 ANTENNAS

CRM-203 in the coastal surveillance application has typical requirements as small target detection in weather and sea clutters and high angular resolution. To provide good angular resolution a narrow azimuth beam is required. A narrow azimuth beam is desirable to reduce resolution cell size for three main reasons:

- to provide accurate bearing information on the target;
- to differentiate between targets which are close together; and
- to reduce clutter returns.

The used system features 12 feet, X-band antennas with horizontal polarisation and the following electrical parameters:

- 3 dB horizontal beam width = 0.7°;
- 3 dB vertical beam width = 22°; and
- gain = 32 dB.

Each antennas group consists of a pedestal supporting the rotating unit. The pedestal contains the drive mechanism, the rotary joint and an 4096 pulses encoder for transmission of antenna position data. The power rating for motor controller is 1.5 kW. Antennas rotating speed is selectable between 12 and 30 rpm. The antennas group is designed to withstand severe marine environmental conditions such as salt spray, sun light, sand, etc.

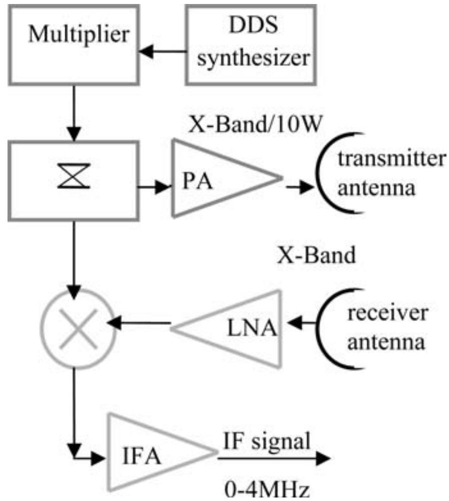

Figure 3. Functional diagram of transceiver unit.

4 TRANSCEIVER

Functional diagram of the transceiver unit is shown on Figure 3. Direct Digital Synthesizer (DDS) produces a synthesized “chirp” (linear frequency modulated) signal. Next this signal is up-converted by multiplier. The last stage of transmitter circuit is solid state power amplifier (PA), which feeds X-band / 10W FMCW signal to antenna. The receiver consists of a low noise amplifier (LNA), image rejection mixer and intermediate frequency amplifier (IFA).

The DDS advantages include very fast switching (typically sub microseconds), excellent phase noise, transient-free (phase continuous) frequency changes, extraordinary flexibility as a modulator, and small size, among others. Frequency changes look like those of a Voltage Controlled Oscillator (VCO) – smooth and without phase discontinuity sweep across a defined frequency range with synthesizer accuracy, but without the glitches and transient produced by any other synthesizer technique. Because of the synthesis techniques, this characteristic is unique to the DDS and enables it to produce a synthesized “chirp”. It is very important in FMCW applications because frequency modulation accuracy is directly influencing on accuracy of distance measurements and frequency modulation non-linearity decreases targets detection.

The proposed transceivers have some additional features which make them specially suited for coastal applications:

- sector blanking: emission can be inhibited within an adjustable sector, so as to avoid undesired returns (e.g. land clutter);

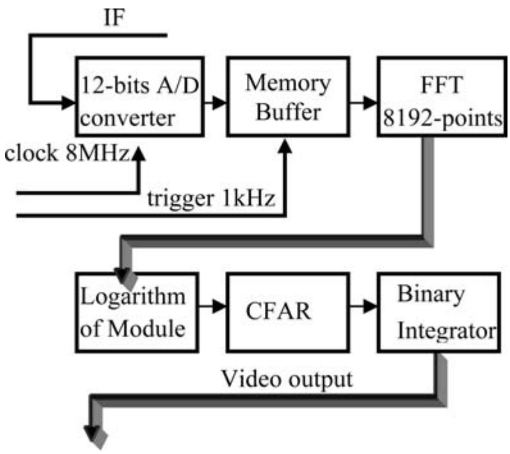

Figure 4. Functional diagram of signal processing.

- 12 dB/okt. frequency curve slope of IFA amplifier ensures equal intermediate frequency (IF) output signals for targets in different ranges; and
- digital automatic receiver gain control function ensures optimal IF signal output level, independently of under detection target radar cross section.

5 SIGNAL PROCESSING AND CONTROL UNIT

5.1 *Functional diagram*

Functional diagram of the signal processing is shown in Figure 4.

The frequency measurement performed to obtain the range measurement is made digitally using the Fast Fourier Transformation (FFT). So the IF signal is digitised and sent to the spectrum analyser that performs FFT. On the input of the signal processing an analog-to-digital converter samples the IF signal with 8 MHz frequency and 12-bit resolution. Next the spectrum analysis of the digitised IF signal is performed on the base of 8192-point FFT. At the output of the spectrum analyser a periodogramm presenting 4096 range cells is obtained. Range cell size is 5.6 m for radar scale range 12 NM.

The signal after the frequency analysis can be best referred as the video signal. The signal is indeed an exact analogue of the video of pulse radar. The range data output from the spectrum analyser is further processed like in pulse radar: CFAR (Constant False Alarm Ratio) thresholding and binary integration during the dwell time on a target are performed.

Spectrum analysis

The IF signal is analysed using FFT transform. The analysis is carried out in real time. The analysed signal can be modelled as a sum of sinusoids embedded in noise and clutter. In FMCW processing scatters at different ranges appear as different constant frequency components at the IF output. The FFT response to a sinusoidal input reveals a main lobe and side lobes. The width of the main lobe indicates Fourier Domain Resolution, which for CRM-203 application is very narrow and equal 1 kHz. This Fourier Domain Resolution or differently bandwidth of FFT frequency cell is very important parameter of FMCW radar, because of detection performance. Probability of detection depends on the ratio of the target received signal level to the sum of clutter and noise. FMCW transceiver noise power N_i is function of the FFT frequency cell bandwidth:

$$N_i = kT_eB_{FFT} \tag{3}$$

where: $k =$ Boltzman's constant; $T_e =$ effective noise temperature; and $B_{FFT} =$ FFT frequency cell bandwidth.

This relationship explains excellent CRM-203 radar noise properties allowing low transmitter power.

5.2 *CFAR thresholding*

The radar must detect a target against a changing background of clutter and noise. The clutter reflectivity and statistics will generally vary with range and direction. The problem is how to set a threshold to provide an acceptable probability of false alarm P_{fd} whilst maximising the probability of detection P_d. Standard detection strategy is to fix the P_{fd}. In CRM-203 application an automatic CFAR detector is used. To control of the false alarms, the detector must be able to estimate the parameters of the probability density function of the clutter and noise returns. A well known method of estimating the clutter mean level is the cell-averaging CFAR circuit. The mean level of the cell under test is obtained from the average of a number of surrounding clutter cells. A gap between the cell under test and the surrounding cells is method to ensure that a distant relative strong target does not contaminate the clutter estimates. In CRM-203 radar smallest off CFAR window is taken to calculate threshold. This strategy helps to detect small targets in neighbourhood of strong clutter region. Size of CFAR window is small so a threshold can follow the local clutter mean and can give a much better performance in detection in our case. After CFAR the binary integrator is used with the "M-of-N" rule in accordance with formulas valid for Gaussian noise.

The Signal Processing & Control Unit includes a local display facility, in order to allow local maintenance and set-up operations. All radar controls are available on the local panel. Moreover SPCU feeds video signal to Radar Display Unit, which accomplish:

- video acquisition and processing;
- plot extraction; and
- tracking.

Track data are sent to the OC for further processing. Also plot information can be routed through the same communications channel. All the radar controls, including those available at the local panel, can be also

Table 1. Transmitter.

Parameter	Value
Output power	1 mW-2 W (switched)
Carrier frequency	9.3–9.5 GHz
Frequency deviation	switched according to the required scale range: 54 MHz at 6 NM 27 MHz at 12 NM 13.5 MHz at 24 NM
Range scales	0.25 NM–48 NM
Modulation	DDS based linear FMCW
Sweep repetition period	1 ms

Table 2. Receiver.

Parameter	Value
IF bandwidth	4 MHz
Noise factor	2 Db
Maximum gain	120 Db
Frequency curve slope of IF amplifier	6 dB/oct; 12 dB/oct; 18 dB/oct.

Table 3. Antennas.

Parameter	Value
Antenna length	3.6 m
Beamwidth (3 dB) horizontal/vertical	0.70°/22°
Polarisation	Horizontal
Gain	32 dBi
Rotation speed min/max.	12/30 rpm
Drive motor	1.5 kW

Table 4. Signal processing.

Parameter	Value
FFT signal processing	8192-points FFT
Sampling frequency	8 MHz
Number of range cells	4096
Signal thresholding	CFAR
Signal integration	binary, number of detections dependent on antenna rotation speed
Sea clutter reduction	signal correlation from 2 antenna rotations.

sent by the OC via the remote interface. The radar continuously sends the status information to the OC, together with target data.

6 TECHNICAL DATA

Basic technical are presented in Tables 1–7.

Table 5. Display unit.

Parameter	Value
Display size	22 inch
Resolution	1280 × 1024 pixels
Acquisition	automatic up to 100 targets
Tracking	automatic of all acquired targets
Zones	2 guard zones
Target information	target number, target range and bearing from radar position, target course
Options	ARPA anti-collision functions

Table 6. Range and angle measurements.

Parameter	Value
Scale range [NM]	12/24/48
Range cell size [m]	5.6/11/22
Range measurement accuracy	1% of selected range or 50 m (whichever is greater)
Angle resolution	0.1°
Bearing accuracy	0.7°

Table 7. Environmental conditions.

Parameter	Value
Wind operational	30 m/s
Wind survival	50 m/s
Humidity	98%, 25°C
Temperature operational	from −10°C to +50°C (inside operating room) and from −30°C to +50°C (outside operating room)
Temperature survival	from −40°C to +65°C

7 RECAPITULATION

Described radar was installed in the radar laboratory of the Gdynia Maritime University this year. Its antenna is located on the roof of the university building nearby the south entrance to the Gdynia Harbour. Operational tests of the radar will be conducted in December 2008. Its detection possibilities, accuracies and clutters resistance will be checked during measurements in real hydro-meteorological conditions. Results will be compared with information about positions, courses and speeds received from Automatic Identification Systems (AIS) installed on board detected and tracked objects and data about these objects received at the same time from four different ship pulse radars installed in the same laboratory. Results of these tests will be presented on the conference.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

5.5 The impact of windmills on the operation of radar systems

M. Džunda, V. Humeňanský, D. Draxler, Z. Csefalvay & P. Bajusz
Faculty of Aeronautics, TU of Košice, Slovakia

ABSTRACT: The contribution provides solutions to the impact of planned building of windmills exerted on the operation of radar equipment. The major negative factors involved have been determined and considered as to how the planned building of wind power stations influences the operation of radar systems developing a procedure of evaluating their effects.

1 INTRODUCTION

The submitted contribution provides one of the possible approaches of evaluating the impact of building windmills (WE) in a given location exerted on the operational parameters of the radio-location system (RLS). For the reason of providing the required coverage the RLS is protected by a protective zone of determined by the distances and height of plains of the protection zone band. If, in the protection zone, there are any obstacles which overlap with the determined planes, then deformation of the RLS coverage in the vertical plane may occur resulting in the loss of radar signal on flying objects.

2 LOSS OF RADIO-LOCATION SIGNALS RESULTING FROM SHADOWING

The importance and acuteness of the mechanism of any impact will depend on the designation of RLS and its operating environment. Among the most important influences of Windmill exerted on the RLS is the loss of signals as a result of shadowing.

The technical data imply the WE has a great cross-section area. In case when locating the WE in the vicinity of the RLS results in late in its shadowing. This is when the radiolocation shadow is generated in the vicinity of the RLS, see Figure 1. The dimension of such areas depend on the size and mutual distances between the WE, their number, distances from the RLS and the surrounding terrain.

If the height of the obstacle at small distances behind the WE exceeds the height of the WE, then the influence of the WE exerted on the reduction of the direct line-of–sight is to be neglected. If the altitude (height above see level) of the obstacle located before the WE exceeds the height of the WE, than the WE has no effect on the direct lined-of-sight of the RLS, which is entirely determined by the dimensions of the obstacle.

The implications of the shadowing can be quite successfully prognosed applying the methods of modeling and simulation. At performing modeling and simulation of the signal loss resulting form shadowing, a special software can be used which is capable of simulating the direct line-of-sight between the RLS antenna and the planned WE. Advantages may result from the use of such software which enable access into the digital model of terrain and thereby modeling obstacles in it.

The results from the simulation will reveal which windmills cause loss of radiolocation signals resulting from shadowing, thereby discarding them from the

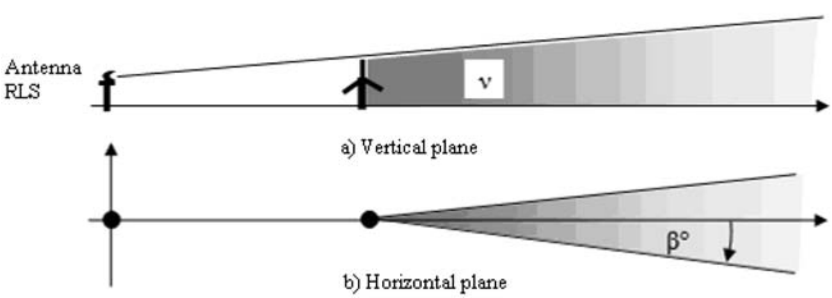

Figure 1. Mechanism of shadowing.

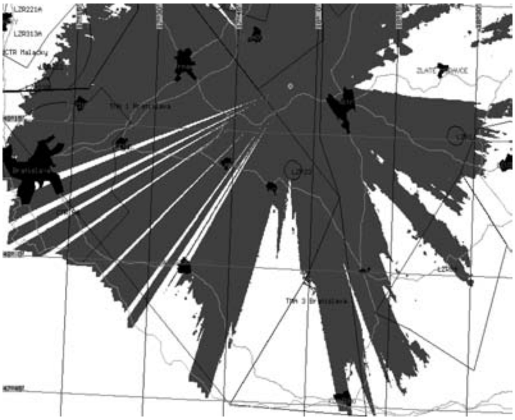

Figure 2. Shadowing of radar signals.

construction plan. The success criterion is the minimally acceptable shadowing that must not be present in the areas of interest.

The influence of shadowing of a WE exerted on the RLS is presented in Fig. 2.

3 MEASURED RADIO-LOCATION SIGNALS AS REFLECTIONS FROM WINDMILLS

Everywhere, where, the RLS is used for local airports, and Terminal control areas (TMA), the reflections from the WE are of the highest importance. It is due to the fact that such reflections may divert the controller's attention and make it difficult for him to monitor further data displayed in the same place on the monitor (Klima trough Bálint). Such an image may also lead to the generation of false tracks of the target which may develop into a more acute problem for air traffic controller. The reflection may cover the targets and the radio-location information on the screen directly over or in the close vicinity of a windmill complex an in some cases may cause the loss of reflections of aircraft.

WE, as specified in the basic technical data section, has a great area of the stand, which is manufactured from conducting material reflecting electromagnetic waves striking it. The non-moving WE stands can be considered for a non-moving (fixed) target. Modern radiolocation systems are equipped with circuits for jamming fixed targets, so we assume that jamming the reflections and WE stands will no longer pose problems, provided that the RLS is operating in the mode of fixed targets suppression. The mechanism of RLS signals is presented in Fig. 3. The precondition of generating such reflections is the sufficient amount of reflected signals, received by the receiver antenna.

We suppose that false targets may result from the reflections from WE which are in direct line-of-sight of the radar. The fact that the WE is situated in the vicinity of the RLS is another precondition.

More complex problems arise in cases when the measured signals are reflected from the propeller

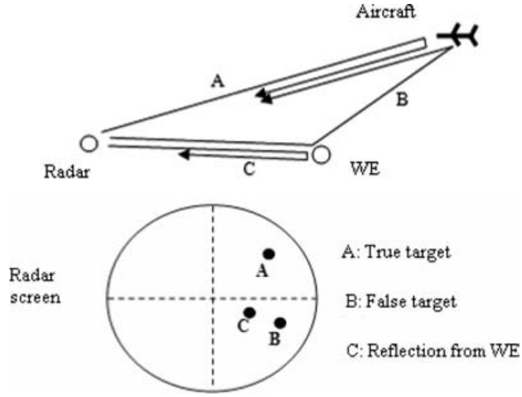

Figure 3. Mechanism of how reflections are generated.

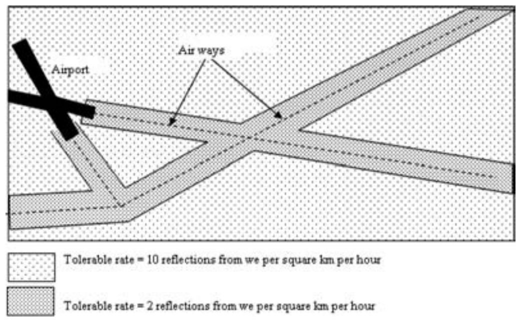

Figure 4. Reflections from windmills.

blades, which, in line with the technical specifications, are designed to have a big area and built form conducting materials reflecting measured radiolocation signals. Under certain conditions, the signals reflected form the propeller blades may be evaluated by the RLS as moving targets.

This rate is to be probably changed along the entire length of the RLS. One of the ways of determining the maximum way of acceptable reflection is the use of so called protection maps.

At such a simplified map, the scales of reflections are seen in Fig. 4.

When evaluating the reflections, we will proceed from the equation:

$$P_{odr} = \frac{P_V G_P G v \sigma \lambda^2}{(4\pi)^3 R^4 L} \quad (1)$$

where L are losses occurring at propagation of the electromagnetic energy in the environment, G_P is the gain on receipt, G_V is the gain in transmission, λ – wavelength, R – distance between the WE and the RLS, σ the effective radar cross-section from which the signal was reflected and P_V is the transmitter performance. The success criterion is termed as the minimum tolerable rate of reflections from the WE per square km in an hour.

4 CONCLUSION

The operation of RLS is negatively influenced by four main factors. Among them are the mistakes in measuring the target azimuth, generation of false targets, loss of signal due to shadowing and degradation of signal as a result of multi-way propagation. When evaluating all the four factors, the key parameter is assigned to the terrain cross section on the connecting line between the WE-RLS and the distance between the wind mill and the radiolocation system. If there is no direct line-of-sight between them, with the distances increasing between them, the effects of building the WE on the RLS are substantially decreasing.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

5.6
3D Sonar for navigation and obstacle avoidance

I. Bowles
FarSounder, Inc. Warwick, USA

Z. Markowski
Escort Ltd. Szczecin, Poland

1 INTRODUCTION

In this changing environmental world of Global Warming, energy exploration and eco-tourism, new [unexplored and uncharted] waters are being opened up on a regular basis.

Here we take the opportunity to look at how an existing technology can be adapted as a useful, important and standard part of the bridge navigation inventory.

FarSounder is a developer and manufacturer of 3D Forward Looking Sonar systems for use as ship borne navigation devices as well as ship borne/shore side security devices. This three dimensional sonar technology offers a paradigm shift in how mariners navigate on the water by economically, accurately and efficiently delivering to mariners the critical information they need to safely navigate their vessels. By providing a real-time, 3D picture of the depths immediately ahead of a vessel, this technology can enable marine vessel operators to avoid costly, dangerous and environmentally damaging collisions and groundings. The introduction of a navigation grade sonar system has an important equivalence to the introduction of marine radar systems during the later part of the 20th century. With the introduction of this enabling technology, these new systems are already changing the way mariners navigate through the oceans.

Figure 1. Victim of an accident in the ice.

Figure 2. Victim of the poor navigation.

2 CURRENT NAVIGATION TECHNOLOGIES

Current navigation technologies, such as GPS, RADAR and electronic charts, are widely accepted and are now required equipment on most classes of vessels. Until now, state-of-the-art navigation has been to rely on historical charts, GPS systems, and depth sounders to determine position and water depth under the ship. Chart data is often inexact as coastlines and shipping channels can shift. Transient objects such as sandbars, lost shipping containers, ship wrecks, whales, floating logs and other debris are not shown on charts. Additionally, many charts can be based on data that is 60 years old or more and predate GPS. This means that even “charted” obstacles are not necessarily where the chart places them.

While an echosounder will tell the ship how deep the water was they just passed through, it can do nothing to warn of the dangers ahead. The radar can only tell the user about objects above the water and give no indication of water depth.

The introduction of and use of navigation grade Forward Looking Sonar is not meant to replace these valuable devices, but rather to augment the mariner’s box of navigation tools by offering a real time picture

Figure 3. Full sonar set.

Figure 4. Transducer usually is mounted in the bow.

of the waters ahead of the vessel. This further enables the mariner to make critical navigation decisions giving a more complete understanding of the real time scenario.

3 CURRENT SONAR TECHNOLOGIES

Until the advent of these new 3D systems, vessel operators were limited to one- or two-dimensional views, with limited distance capabilities, limited performance in shallow waters, and a narrow field of view. Usually these products are from a recreational, fishing specific or hydrographic market, and therefore not suited for commercial applications or useful navigational purposes; yet they may still be marketed and sold for this purpose. At the other end of the spectrum there are military grade sonar systems, that again, are designed for a specific market capability. They also tend not to be commercially viable navigation options for a commercial vessel operator.

Although customers of these other systems understand the need, these products do not solve the problem.

4 PRINCIPLE OF OPERATION

The 3D sonar is comprised of a phased array transducer that will usually be mounted in the bow or stem of the vessel, facing forward. This in turn is connected by a special cable to a junction box and from there to the processor on the bridge.

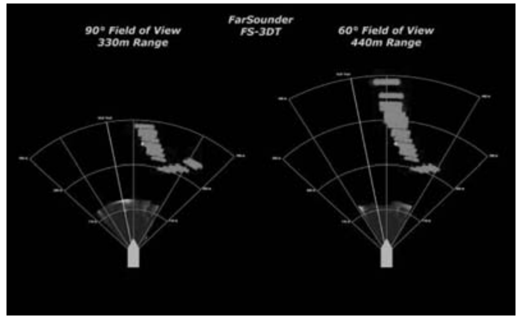

Figure 5. Sonar display 2D view.

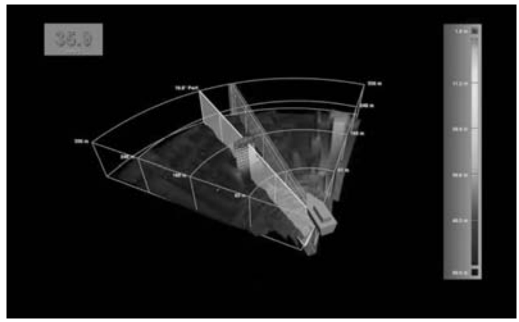

Figure 6. Sonar display 3D view.

Figure 7. Breakwater in front.

The forward looking horizontal field of view is a practical 60° to 90° with a range of ¼ nm. Development is currently underway to introduce ½ nm system during mid 2009. Vertical field of view is approximately 10° up to the surface and 50° down. The whole volume is pinged every second with an overall refresh of around 1.5 to 2 seconds giving a virtual real time presentation.

The advantage of three dimensions is that the vertical dimension of depth is now added to the range and bearing information.

Shallow water operation is also greatly improved. With bottom mapping capability of 8 × the depth of water (in practice 10–12×), "in water" targets can still be detected to the full range of the system.

An easy to use man machine interface allows for easy interpretation of essential data.

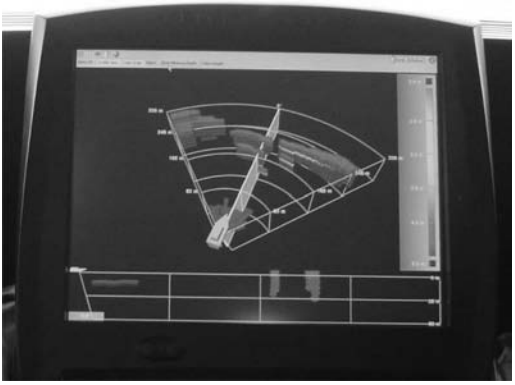

Figure 8. Barrier echogram in 3D.

Figure 9. Victim of the ship strike.

In a comparison of the visual picture vs sonar, the below example shows a breakwater as seen through the bridge windows and the same view on the 3D Forward Looking Sonar.

It is clear on the sonar display that there are other obstacles in front of the breakwater but below the surface.

5 ENVIRONMENTAL CONCERNS

Shipstrike is the largest killer of the endangered Right Whale and the Great Whale. At certain times of the year during migration patterns, certain ocean areas are now restricted for passage or by significantly reduced speeds.

It is also commonly reported that sonar is harmful to marine mammal life, and it needs to be clarified that this is often in relation to low frequency and high power systems used predominantly for military applications.

FarSounder sonar systems should not be confused with these other sonar systems.

"NOAA's Ocean Acoustics Program (NMFS Office of Science and Technology) has assessed the technical specifications of the current version of the FarSounder sonar technology and concurs that, based on the sound source level, signal duration, directionality, and operational frequency band, there are no anticipated

Figure 10. Victim of the bow strike.

Figure 11. Quieter than a dolphin and in the same frequency range as other accepted marine electronics.

injurious effects on marine mammals or other marine species from it's deployment."
Brandon Southall, NMFS

"The FarSounder, high frequency, active sonar technology may provide an effective tool in alerting mariners to the presence of submerged, or surfacing, animals in sufficient time to avoid collisions."
David Potter, NMFS

6 INTEGRATION

3D sonar data can now be integrated into today's so phisticated bridge management systems and was the next logical step. Today's IBS can now have sonar overlay as an option to the radar overlay on the electronic chart.

With the advent of Voyage Data Recorders, more and more recording capability is often sought. Sonar data is no different and can also be archived, either directly or in conjunction with the VDR.

7 LIMITATIONS AND EXPECTATIONS

Targets such as containers, whales, rocks, reefs, ice/icebergs, other vessels, buoys, pilings, etc. (to an

Figure 12. Catamaran equipped with 3D sonar.

Figure 13. Transducer installed on the bow of a hulk.

8 dB target), are the benchmarks for the types of targets that can be expected to be detected.

Limitations for commercial vessel operators of all classes are usually related to speed and range. Larger vessels and High Speed vessels need sufficient time to evaluate potential dangers and act accordingly, although for vessels at manoeuvring speeds, the range requirement is significantly less.

Current vessel speed for both the ¼ and ½ nm systems is up to 20 to 25 knots. Future research and development over the next 1.5 to 2 years anticipates ranges of 1 to 2 nm and a speed up to 35 knots.

8 CHALLENGES

In regards to the development of a long range/high speed navigation sonar as discussed above, there are specific physical (scientific) challenges that must be dealt with that are of minimal effect on the current shorter range systems.

For instance, there is a trade-off in choosing an appropriate frequency which will still offer enough signal to noise ratio (SNR) to counter the effects of long range attenuation of the system.

At higher speeds, a challenge to overcome may be hull specific in dealing with high speed flow noise issues. Therefore, the form factor of the Transducer Module and how it is mounted must be carefully chosen for different high speed hull types.

At short ranges it may be appropriate to regard the Sound Speed Profile as a constant (for navigation grade sonars, not necessarily for security sonar systems). At longer ranges, a vertically varying sound speed profile must be compensated for.

The resolution of Long Range Targets is also a challenge and requires an added level of Bathymetric Testing and Ground Truthing as well as compensation in the Fixed Frame of Reference.

9 OTHER APPLICATIONS

Future Security Applications: One of the greatest threats to passenger vessels is an attack by swimmers, divers, or other underwater threats. Various technologies enable surveillance and deliver security against air and land attacks, but there is a lack of a low-cost practical and effective solution to detect or deter an underwater based attack, particularly one by swimmers. Underwater security is one of the most technologically challenging. Threats below the water are difficult to address.

There is a current need in the industry for an accurate, easy to use, low cost system with 360-degree sector coverage. Three dimensional forward-looking sonar technology can be very effectively applied to solve this need and to combat these possible attacks.

10 CONCLUSION

The need for a navigational solution to groundings and collisions has been recognized for hundreds, if not thousands of years. We expect that navigation grade sonar will become increasingly attractive to operators of all large ships. Three dimensional sonar technology represents an extraordinary advance in sonar technology, and represents a revolutionary change in the way vessels navigate.

Link to download a demo of the operator software http://www.farsounder.com/products/demo

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

5.7
The problem of magnetic compass deviation at contemporary conditions

E.M. Lushnikov
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: The problem of accuracy magnetic compass for contemporary condition is described. The technique of actualization of deviation's table at conditions of voyage is offered. The methods and means of actualisation is described also.

1 INTRODUCTION

According to requirements of Register the table of deviation is legitimate during 1 year after compensation of deviation, however, at navigation in ice or in storm conditions it can be not actual already after some days of navigation. It cannot be guarantee for high accuracy compass during one e\year at all conditions.

The role of a magnetic compass at the modern vessel today is reserving of navigation. This role of magnetic compass is explained by means of high accuracy of gyrocompass and high accuracy of GPS receiver. Such decrease in a role of a magnetic compass is involuntarily reflected in carefulness of his service.

At the same time, normative documents do not provide any indulgence to quality of the maintenance and service of compasses, including to quality of deviations service.

It is known, that if expensive services do not raise efficiency of works them try to avoid by every way. It now occurs on fleet regarding carrying out deviation's works, that, certainly, does not promote a safety of navigation.

Today the navigator has such technical and theoretical base, that he can possibility to provide carrying out the deviation's works itself, but he is not accustomed to this during all history of fleet development. He prefers to pay, especially not from the pocket.

The passive relation of the navigator to monitoring and compensation of deviation is explained by the complication of contemporary methods. It is necessary for stimulation of navigator to monitoring of compass the new effective and simple methods which are not demanding essential time expenses.

2 THE ANALYSIS OF DEVIATION'S FACTORS AT CONTEMPORARY SHIPS

The analysis of stability of deviation's factors [2] shows, that factors *A* and *E* for contemporary vessels practically do not exceed $0,6^0$ and are very stable. Not compensated factor *D* for new building ship always is positive and is in limits $3^0 \div 5^0$. The factor *D* is high stability.

As a rule, at annual compensation of deviation only the least stable factors of deviation *B* and *C* is compensated and under compensation the table of deviation is anew recalculated entirely.

The modern methods of deviation's works are carried out usually according to the hard algorithms which are not admitting any variations and the account of concrete circumstances.

Actually on the vessel at practically constant factors A, *D* and E from year to year are anew determined all factors of deviation and the table of deviation is recalculated. It happens even so, that factors again accepted to the account A, *D* and E have accuracy below, than it was in the old table. It is explained, first of all, that values of these factors are commensurable with a margin error their calculations.

It turns out so, that annual determinations of factors A, E and *D* at their small value and high stability it is inefficient expenditure of time and resources.

At typical procedural deviation's works the factors B and C of half circle deviation are compensated. Obviously, it is necessary to use elastic algorithms for counting these changes.

At such state there is a question about expediency of compensation of factor B and factor C up to zero. If the factor B and C to return to former tabulated values position, that there is not necessity of recalculation of deviation's table anew.

3 THE ACTUALISATION OF DEVIATION'S TABLE AT CONDITION OF VOUAGE

At the same circumstances all deviation's work can be executed for example at the course N and E, instead of twelve courses as it take place at typical procedural works. Thus, the time of manoeuvres can be reduced in 6 times. This prize is rather essential.

In addition from process of deviation's works it is excluded the cultivation of measuring information and calculation of the new table of deviation. The old table of deviation is prolonged for new term. Instead of one and a half hours of time without taking into account expenses for transition up to special aquatory and back it is enough to spend $10 \div 15$ minutes of time without any calculations.

The sequence of operations is according to:

- The deviation of magnetic compass is determinated at the compass course 0^0. If the value of deviation is differed from tabulated value less than $0,5^0$ it is not necessity of correction. If the different of deviation is more than $0,5^0$ it is necessary to recover the value of deviation from the table.
- The deviation of magnetic compass is determinated at the compass course 90^0. If the value of deviation is differed from tabulated value less than $0,5^0$ it is not necessity of correction. If the different of deviation is more than $0,5^0$ it is necessary to recover the value of deviation from the table.
- The time of correction must be written at the table. The signature of executor must be at the table also.

Such simplified way for correction of half circle deviation demands enough solid data about magnetic declination. From this reason the choice of a place for carrying out of such works it is necessary to avoid areas of magnetic anomalies, etc.

4 THE REQUIREMENT OF ACCURACY AT ACTUALISATION OF A TABLE

The deviation of a magnetic compass is determined from one of a formulas:

$$D = TC - CC - V$$

$$D = TB - CB - V$$

From these formulas it is visible, that accuracy of determination of deviation and also accuracy of restoration of its former value depends, first of all, from accuracy of knowledge *TC* or *TB* and from accuracy of values of variation V. The standard error of restoration of deviation up to its tabulared value is determined accordingly on one of formulas:

$$m_D = \sqrt{m_{TC}^2 + m_{CC}^2 + m_V^2}$$

$$m_D = \sqrt{m_{TB}^2 + m_{CB}^2 + m_V^2}$$

Such simplified procedure of deviation’s works reminds inherently a computer option “restoration of system”. This option very much frequently helps users of personal computers, allowing to return the lost elements of system “Windows”, due to periodic automatic records of installations of system.

If to carry out this analogy, that the values of deviations on the course N and E represents the written down(at the table) values of deviations. This value is nominative to restoration.

Comprehension of such fact allows the navigator widely using a computer in the daily practice, to find for an offered method a corresponding place in uniform philosophy of maintenance of navigating safety of navigation.

5 CONCLUSION

Such simplified method of restoration of a urgency of the out-of-date table of deviation can be made within $4 \div 5$ years if not it was made significant repair work.

Such statement of a question will allow to harmonize expenses for maintenance of efficiency of a magnetic compass and feedback from its party, both in aspect economic, and in aspect of safety of navigation.

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5.8
The basic research for the new compass system using latest MEMS

G. Fukuda & S. Hayashi
Tokyo University of Science and Technology, Tokyo, Japan

ABSTRACT: This paper demonstrates basic research for a new compass system using latest MEMS (Micro Electro Mechanical Systems) sensors for small vessels. In 2007, MEMS Electro-statically Gyro (ESG) was introduced by TOKYO KEIKI which is a Japanese company. This sensor accuracy has dramatically improved compared to vibration types. For example, instability has been improved 10 times more than the vibration types. The reproducibility was tested and maximum difference was 0.55 [deg/sec] in the field test. The MEMS-ESG could detect the relative angles as accurate as GPS compass in short term use. Even though sensor accuracy has been improved, an improvement of another 10 times is needed to detect the earth's turn rate. Because of this a second system is required for a complete compass system. A celestial navigation system is one of the possibilities to complement this. Traditionally the sextant has been used for measuring the altitude, but it has some human errors and difficult to measure continuously. Therefore, it might be useful to get sun altitude and direction automatically. In this thesis, the sun altitude and direction detecting system using camera devices are studied. Using 350 × 288 resolution camera and a radio-controlled clock, the sun movement was detected 5'14" per pixels and 2'16". per pixels for the altitude and direction respectively. Although this is a basic research for an integrated system, the data should have an enormous affect upon future research.

1 INTRODUCTION

1.1 *Background of the research*

Small vessels have a choice of Gyro compass, magnetic compass or GPS compass. They are also using the GPS for calculating positions.

Even though GPS is very accurate, small and low cost, it needs signals from satellites. Because GPS is worked by external signals from satellites, several weak points have been discussed, for example, jamming, maintenance cost, electromagnetic wave by the sun and etc. Therefore for the purposes of this research we studied an autonomous system without using GPS.

The Inertial Navigation System is an autonomous and overcome the problems that are caused GPS. In the recent technological advancements modern inertial systems have removed most of the mechanical complexity of platform systems by having the sensors attached rigidly to the body of the host vehicle. It is called the strapdown inertial navigation system. But to maintain its accuracy, it still needs very accurate systems such as the ring laser gyro (RLG), the fiber optic gyro (FOG) or more accurate gyro such as the electro-statically suspended gyroscope (ESG) and also very complex systems. Those systems are expensive and uneconomical for small vessels but new type of MEMS sensors should provide a possible solution to this problem.

In this research, the basic researches were carried out for the stated goal that is developing a small and low cost autonomous system which is affordable for small vessels.

1.2 *The integrated compass system*

MEMS-ESG is able to detect relative angles which discussed in this paper. For the compass system, absolute angles are necessary. Therefore integrated system was being looked at. The considering system is using INS with MEMS-ESG and sun direction and altitude detecting system using camera image. The system diagram is shown in Figure 1.

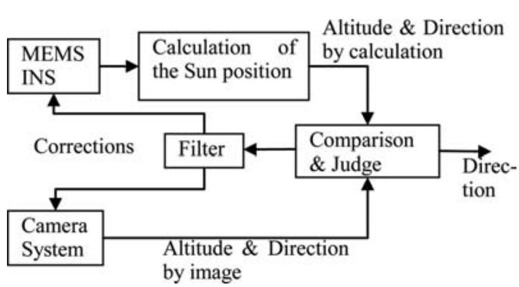


Figure 1. Integrated Compass System.

INS using MEMS-ESG is able to navigate for only 2 minutes or less, Gen F. & Shogo H., 2008. One of the problems is cumulative errors. There for the camera system update time should be within that time.

In this thesis, the MEMS-ESG is introduced in the second paragraph and then the camera system is introduced in 3rd paragraph as basic research for the integrated compass system.

2 MEMS ELECTRO SUSPENDED GYRO SENSOR

2.1 *The basic research of MEMS-ESG*

The ESG is introduced during the 1950s in the United States. The ESG is very accurate and it has achieved drifts of the order of 0.0001[deg/h] and navigation accuracies of the order of 0.1 nautical miles per hour, David Titterton and John Weston. 2004. Unfortunately, despite being very simple concept, the design is complex and the gyroscope is large and expensive.

The MEMS-ESG was introduced by a Japanese company in July 2007. Although the accuracy is not the same as the previous ESG, its accuracy is greatly improved as MEMS gyro sensors. Additionally it is lower price than the previous ESG.

The MEMS-ESG is measuring the turn rate using the turning sensor rotor which is suspended by electrostatic power. When the turn rate is applied to the rotor, a slight tilt angle is occurring between sensor rotor and sensor case. A feedback torque is applied in order to return the rotor to the normal position. This feedback torque is proportional to turn rate, so the sensor can detect the turn rate. In addition, the sensor detects the 3-dimension accelerations by the torque which is applied for maintaining the sensor rotor in the center of the case.

The MEMS-ESG sensor structure has 3 layers that are glass, silicon and glass. The sensor structure image is shown in Figure2. The sensor size details are shown in Table1. Picture 1 shows the sensor package. The package is 4.3[mm] squared and 1[mm] thickness, Shigeru Nakamura. 2008.

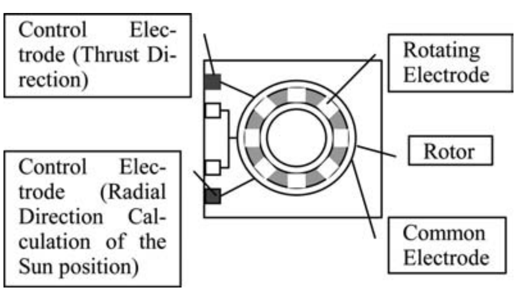
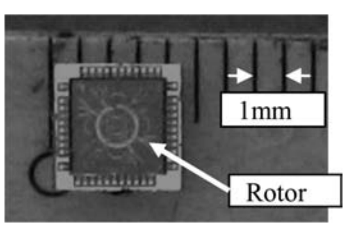


Figure 2. MEMS-ESG Sensor Structure.



Picture 1. MEMS-ESG Sensor Package.

2.2 *Rate Output*

Figure 3 shows 100 data of the angular velocity output about X and Y axes by MEMS-ESG. The data was collected in the laboratory in stable conditions. The vibration type gyro sensor's output was collected at the same time. The comparison of the MEMS-ESG with vibration type is shown in Fig 4. In this case, the average output of rate sensor by the MEMS-ESG and a vibration gyro are 2.844×10^{-17}[deg/sec] and 0.131[deg/sec] respectively. Instabilities are 0.260[deg/sec] for MEMS-ESG and 3.125[deg/sec] for a vibration gyro.

Table 1. Rotor information.

Rotor diameter	1.5[mm]
Thickness	50[μm]
Top and bottom gap	3[μm]
Radial dimension gap	2.5[μm]

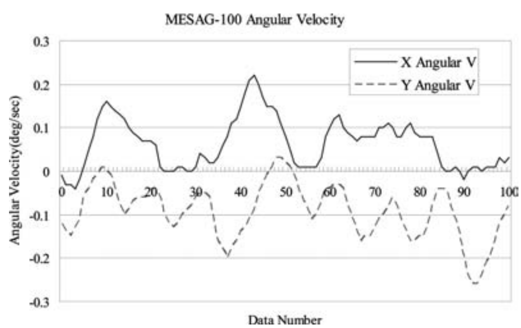


Figure 3. X and Y axes angular velocity output by MEMS-ESG.

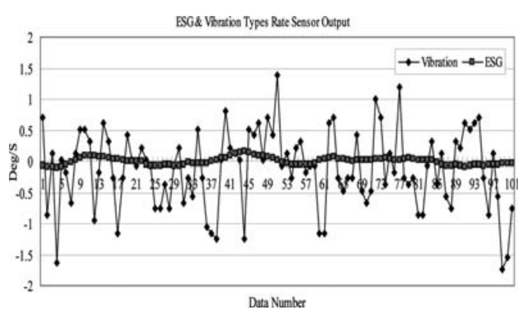


Figure 4. Comparing Vibration with ESG type.

2.3 *Reproducibility test*

Ten times relative angle reproducibility test was carried out. The sensor was rotated about 90 degrees by motor and stopped mechanically by using a relay switch. Figure 5 shows the test result. The data shows good reproducibility in short term use. The biggest difference of this data was 0.550 [deg/s] around the sensor stopped point which is shown in Figure 6. It was considered that that difference was caused by the small vibration caused by the reaction of the mechanical stop.

2.4 *Acceleration output*

It is shown the X-axis acceleration output in the stable condition in Figure 7. The compared with the vibration type acceleration sensor was shown in Figure 8. In this figure, the average output of acceleration sensor output by MEMS-ESG and vibration are -1.215×10^{-18}[G/sec] and -0.002[G/sec] respectively. Instabilities are 0.002[deg/sec] for MEMS-ESG acceleration sensor and 0.053[G/sec] for vibration acceleration sensor.

2.5 *Comparing with GPS compass*

The comparing test was held using GPS compass. The GPS compass was fixed on the MEMS-ESG and both equipments are rotated simultaneously by DC motor. The equipment was shown in Picture 2.

Figure 9 shows the relative angle by the MEMS-ESG and GPS compass output. The MEMS-ESG is able to measure the turn rate as accurate as the GPS compass in short time use. The GPS compass data has some data blanks since the GPS compass could not get the signal from the GPS satellite, whereas MEMS gyro is able to get the data continuously. This result might suggest that the GPS/INS is very useful in some areas.

2.6 *Existing problems with MEMS-ESG*

The MEMS accuracy improvement was discussed in 2.2 and 2.4 by comparing the ESG type sensor and the vibration type. ESG type is very useful concerning its accuracy but it requires some techniques to provide shock and vibration protection. The vibration type gyro sensor which discussed in this paper has 2000 g-powered shock survivability, but ESG type has got

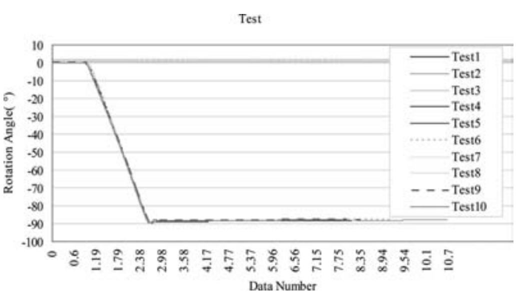


Figure 5. Ten times relative angle reproducibility test.

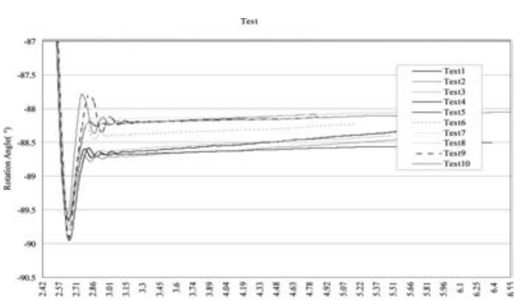


Figure 6. The enlarged figure of vibration point.

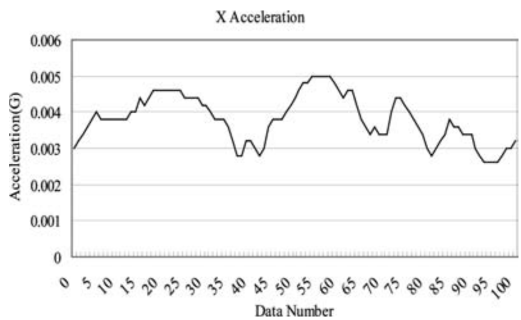


Figure 7. X-axis acceleration output.

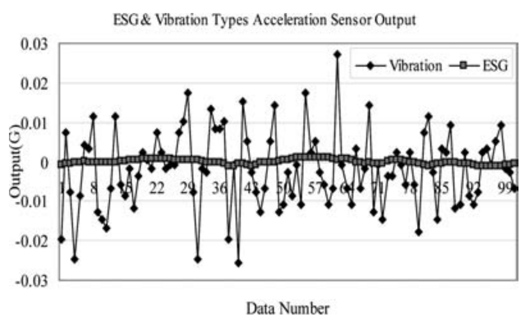
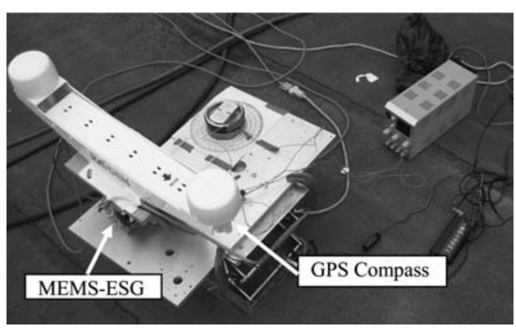


Figure 8. Comparing Vibration with ESG type.



Picture 2. GPS compass and MEMS-ESG for the comparing test.

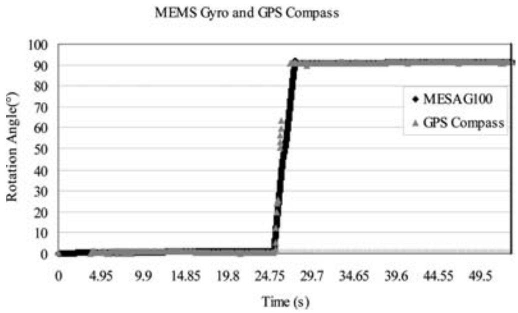


Figure 9. MEMS Gyro and GPS compass Output comparison.

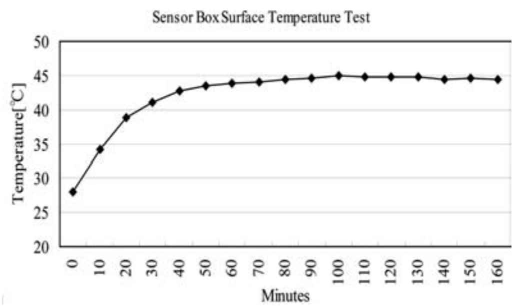


Figure 10. Sensor Box Surface Temperature Test.

only ±15[G] at 1[kHz]. For example, when we carried out field test by the car, the sensor was sometimes stopped because of the light shock by the brake. This problem is reported not only MEMS-ESG but also the normal type of ESG gyro as well. Before considering using the MEMS-ESG on a ship, this problem must be solved.

Moreover, the sensor box surface temperature is increased as shown in Figure 10. The test was carried out in the laboratory where the temperature was 27.5[°C]. The sensor box surface temperature was increasing and reached 44.8[°C] in 110 minutes. This was caused mainly by FPGA (Field Programmable Gate Array) in the sensor box. This is not directly caused by sensor itself but concerning affordable sensor temperature which is from −20[°C] to 55[°C], it would be necessary to resolve this problem in some environments.

3 SUN DIRECTION AND ALTITUDE DETECTING SYSTEM USING CAMERA IMAGE

3.1 *The general outline of the system*

MEMS-ESG is capable of detecting relative angles. But it also needs to know the absolute angles for the compass system. Therefore second system is needed. Gyro compass has normally been used for that. But it is expensive and too big for small vessels. The magnetic compass, the celestial navigation and the terrestrial navigation are traditionally used on the ship. The magnetic compass is one of practical solutions but it has got the problem of deviation. The celestial navigation is also powerful tool but it needs to detect the altitude using a sextant by hand. This would cause the human factor errors. It is also difficult to observe continuously. But considering the celestial navigation is still using on some ships for a complement of GPS, it is still useful if it is automated. There is available radio sextant as an automated system for this but the equipment cost is too expensive. Therefore the web camera was considered to measure the sun altitudes and directions. According to recent development of imaging device, they are getting cheaper and higher resolutions. There is the system using CCD cameras, Fabio C. & Erik K., 1995. But high resolution CCD cameras are still expensive.

3.2 *Direction and altitude calculation*

The system needs to calculate the sun position. It needs very complicated calculation to get the real sun position. Therefore the calculations have been completed using a polynomial approximation of ephemerides, which was invented by Hydrographic Office of Japan, Japan Coast Guard. 2008. It would be considered that there are slight differences between a polynomial approximation and Nautical Almanac. If using high resolution cameras, those difference are should be considered.

3.3 *Camera device*

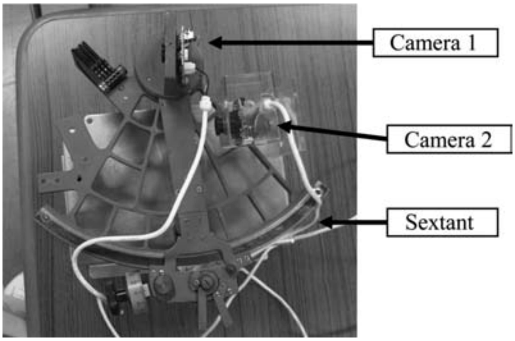
There is the system using fisheye lens, Matthew C. D., David W. & Daniel V., 2005. The fisheye lens is very useful because it could detect the sun only one camera without any mechanical moving devices. But there are few fisheye lenses for web cameras. They also need many calibration works.

Therefore two cameras are used in this system. They are 352 × 288 pixels web cameras and put on the sextant for evaluation as shown in Picture 3. Camera1 expected to take sun image and camera 2 is expected to take horizon. Both cameras are connected with PC by using USB cables.

3.4 *The result*

The calculation for the altitude and direction is produced by Kenji Hasegawa, 1994. The result of sun altitude by calculation and camera image for 22 minuets are shown in Figure 11. Figure 12 shows 500 data in Figure 8. The sampling time is 0.5[sec]. The time was given by a radio-controlled watch. There are two flutters which show in Figure 12 around at 14:53:3 and 14:54:40. This would be caused by the interlace scan.

The maximum difference and standard deviation with calculated data and camera image data are 0.0932 degrees and 0.0246 degrees respectively. The calculated sun altitude is moving uniformly, as you would see in Figure 12. But the altitude by camera image is



Picture 3. Camera Device used the evaluation.

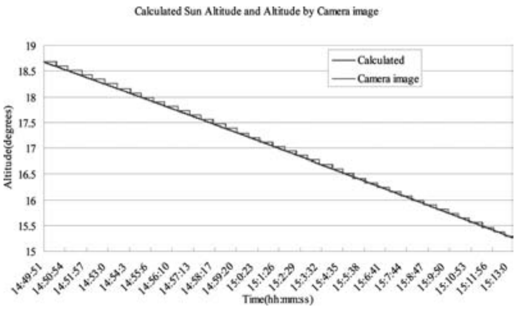


Figure 11. Calculated Sun Altitude and Altitude by Camera Image.

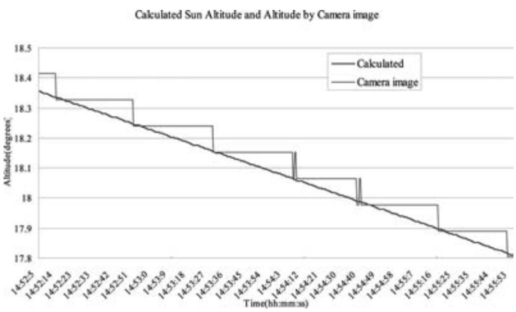


Figure 12. The 500 data in Figure 11.

moving like steps. This is caused by the camera resolution. In this case, it is detected 0.0872 [degree/pixel], which is equivalent to 5’14”.

The results of sun direction by calculation and camera image are shown in Figure 13. Figure 14 shows 500 data in Figure 13. A sampling time is 0.5[sec]. The time was given by a radio-controlled watch.

The maximum difference and standard deviation between calculated data and camera image data are 0.0647 degrees and 0.0054 degrees respectively. The resolution is detected 0.0378 [degree/pixel], which is equivalent to 2’16”.

The reason of resolution difference between Altitude and Direction was caused by the initial camera attitude error. Further more, the camera focus error is considered as the error term.

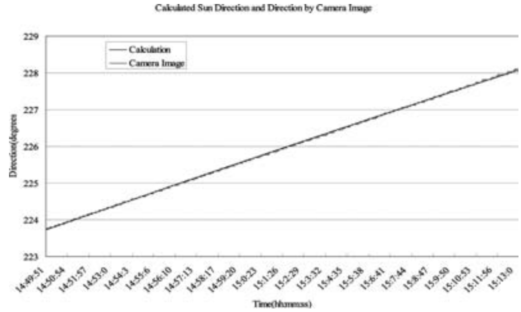


Figure 13. Calculated Sun Direction and Direction by Camera Image.

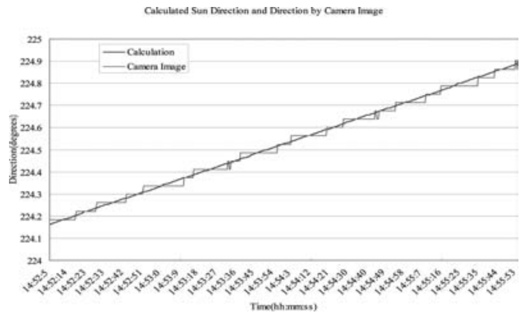


Figure 14. The 500 data in Figure 13.

4 FUTURE WORKS

A position data is demanded for the calculation of sun altitude and direction. The MEMS INS is possible way to calculate the position. The MEMS INS is demanded to keep its accuracy while the camera system is updating the sun position and altitude. Using the camera system in section 3, more than 2 minutes updating time is demanded. Therefore the INS using MEMS-ESG needs more accuracy, Gen F. & Shogo H, 2008. Many books are published for the INS calculation such as David Titterton and John Weston. 2004. But those calculations are considering more accurate sensors. Now, the INS program for the MEMS-ESG is under researching.

There is accuracy difference between the X-axis and Y-axis. This difference might be caused by the CMOS sensor in the camera and also initial alignment errors. The studies have been undertaking about it. In addition to that, the research using higher resolution web camera is also undertaking.

5 CONCLUSION

In this paper, the new type of MEMS sensor, MEMS-ESG, and the sun altitude and direction detecting system were explained as basic research for the new compass system using latest MEMS.

An accuracy of MEMS-ESG has much improved comparing previous vibration type of MEMS sensors. The sensor's reproducibility was explained. Furthermore, the relative angle accuracy was shown comparing with GPS compass. The problem of MEMS-ESG is explained in 2.5. Especially, some countermeasures are needed for the shock survivability on the ship. Although there are still some problems with MEMS-ESG, it has got much potential. The vibration type sensors would be difficult to increase their accuracy because of their structures. However, ESG type has different structures and easier to increase its accuracy. For example, inertial momentum is proportional to the square of rotor's diameter and also rotor's rotation rate. To consider those and the fact that the company has already made successfully the bigger diameter rotor sensor, MEMS-ESG accuracy would be increased in the future.

In 3rd paragraph, the sun altitude and direction detecting system using camera image was explained. Using 352×288 resolution web camera, the accuracy achieved 0.0872 [degree/pixel] for the altitude and 0.0378 [degree/pixel] for the directions.

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5.9
Development of decision supporting tools for determining tidal windows for deep-drafted vessels

K. Eloot
Flanders Hydraulics Research, Antwerp, Belgium
Ghent University, Ghent, Belgium

M. Vantorre & J. Richter
Ghent University, Ghent, Belgium

J. Verwilligen
Flanders Hydraulics Research, Antwerp, Belgium

ABSTRACT: A decision supporting tool named ProToel for determining tidal windows for deep-drafted vessels arriving at or departing from the Belgian harbours, based on both deterministic and probabilistic criteria, has been developed. The program is presently being evaluated as a short-term decision tool by the pilots and waterways authorities for optimising the shipping traffic to the coastal harbour of Zeebrugge. The software can also be applied for long-term considerations, as is illustrated in the case of the port of Antwerp. Some reflections are made considering the extension of the tool to include other factors that may affect the safety of shipping traffic, such as interaction with banks and with other shipping traffic.

1 INTRODUCTION

Access channels to harbours are often subject to tide, so that arrival and departure of ships may be limited to a certain window. This window is mainly determined by the variations of the water level and is therefore of particular importance for deep-drafted vessels, but also other parameters such as lateral and longitudinal current components, or penetration of the keel into soft mud layers may be limiting factors.

In particular, tidal windows have to be imposed to deep-drafted ships arriving at and departing from the Belgian seaports of Zeebrugge and Antwerp. The *Scheur West* channel links the deeper *Wandelaar* area in the southern North Sea via the *Pas van het Zand* to the port of Zeebrugge, and via the *Scheur East* and *Wielingen* channels to the mouth of the river *West Scheldt*, which gives access to the port of Antwerp, where deep-drafted ships can either berth on one of the river terminals or the tidal *Deurganck Dock*, or enter the *Zandvliet* or *Berendrecht Locks*.

For the sea channels giving access to the Belgian harbours, a decision supporting software tool has been developed. This tool results into an advisable tidal window, based on a number of criteria that can be both deterministic and probabilistic. In a deterministic mode, the gross under keel clearance (UKC), relative to both the nautical bottom and the top of fluid mud layers, and the magnitude of current components are taken into account. In case probabilistic considerations are accounted for, a positive advise will only be given if the probability of bottom touch during the voyage – due to squat and response to waves – does not exceed a selected maximum value. The following input data are taken into consideration: ship characteristics, waterway characteristics, trajectory, nautical bottom level, top mud level, speed over ground and through the water, tidal elevation, directional wave spectra, current, departure time.

The tool, called *ProToel*, can either be used for supporting short term decisions for a particular ship, or for long term estimations for the maximum allowable draft. *ProToel* is presently in an evaluation phase for supporting decisions taken by the Flemish Pilotage and Shipping Assistance in a short term approach for ships arriving at and departing from the harbour of Zeebrugge. For the harbour of Antwerp, to be reached by sea channels and the river Scheldt, the program can also be used as an approach policy supporting tool for long term considerations; extensions to support short term decisions are considered.

A description of the *ProToel* software will be given, followed by practical examples of its use for determining tidal windows for ships arriving at or departing from Zeebrugge. Next, some applications for the shipping traffic to Antwerp will be considered, and finally possible extensions will be covered.

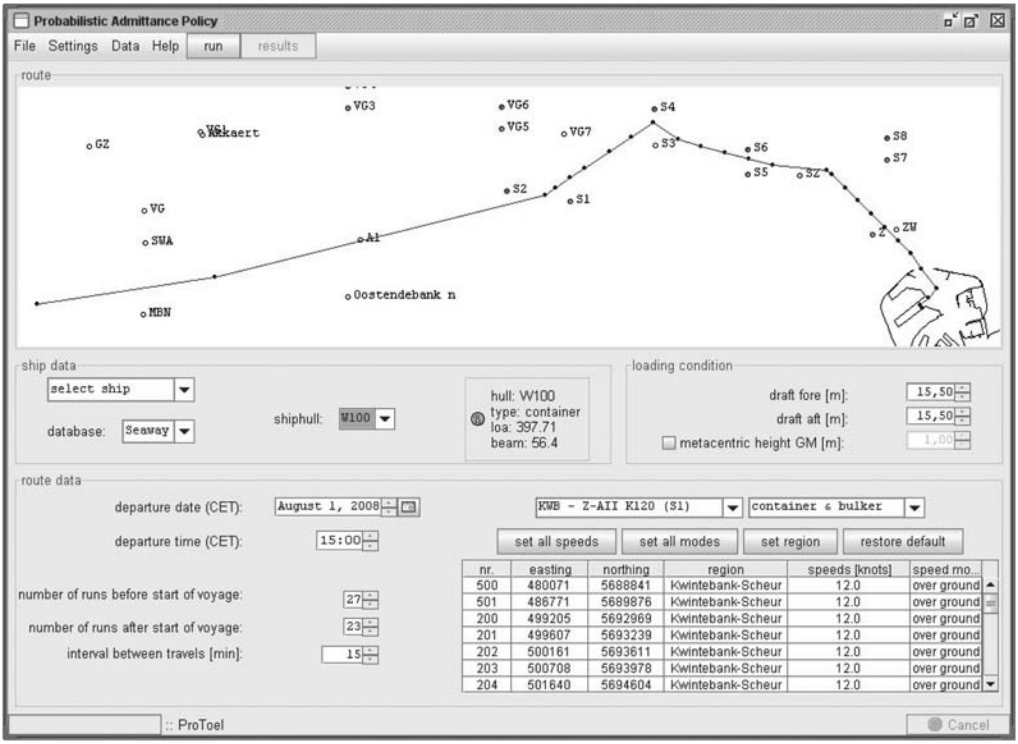


Figure 1. ProToel's graphical user interface.

2 DESCRIPTION OF THE PROTOEL SOFTWARE

2.1 *General principle*

Based on a specified route and departure time, the ProToel program calculates the UKCs and bottom touch probabilities for a specific ship following the route with a chosen speed along the trajectory. The route is split into several intervals. In each interval, the UKCs are calculated based on bottom depth, up-to-date current and tide data and the speed dependent squat. The bottom touch probability is calculated from the directional wave spectrum for that time, location and the motion characteristics of the ship. The results for each interval are stored and can be displayed after computation.

ProToel requires the availability of a number of databases:

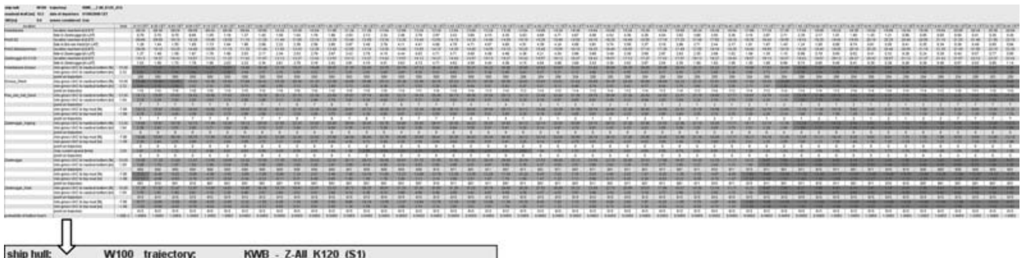
- a ship database with dynamic response characteristics and squat data for a large range of ship dimensions and types, valid for a realistic range of forward speeds, drafts and water depths;
- a database of trajectories and trajectory points, containing recent soundings (or design depths);
- forecasts or measurements of hydro-meteorological data for a number of locations as a function of time: tidal elevation, current speed and direction, directional wave spectra, water density.

The software is developed in an object oriented programming environment, making use of Java.

2.2 *Operational use*

The graphical user interface (GUI), see Figure 1, allows an easy selection of the desired ship, represented by her beam and length. The user specifies the loading condition, namely the draft at the fore and aft perpendicular and optionally the metacentric height. Furthermore, the time of departure, the route to follow and the speed of the ship along this route – either through water or over ground – are inserted. Additionally, a number of travels can be specified before and after the desired time of departure to create a tidal window, based on a number of deterministic and/or probabilistic criteria. The menu allows specifying the data source (locally stored data, remote data) of each environment condition (tidal elevations, current, waves, bottom) separately. Recent predictions and measurements of tide, waves and current are stored in a remote database on a server that can be connected by the user, while a local database may contain long-term predictions, e.g. astronomic tide data.

The output of the computations is stored in xml format and contains the UKCs and cross currents at significant locations along the route. If a probabilistic approach is chosen, the bottom touch probability for the entire route is also given. The results can be viewed



ship hull:	W100 trajectory: KWB_-_Z-All_K120_(S1)			
maximal draft [m]: 15.5	date of departure: 01/08/2008 CET			
GM [m]: 0.0	waves considered: true			
location		limit	8:15 CET	8:30 CET
Kwintebank	location reached at [CET]		08:24	08:39
	tide in Zeebrugge [m LAT]		0.70	0.70
PvhZ-SZ	location reached at [CET]		09:40	09:55
	tide in Bol van Heist [m LAT]		1.29	1.44
PvhZ-Strekdammen	location reached at [CET]		09:55	10:10
	tide in Zeebrugge [m LAT]		1.37	1.49
Zeebrugge A2 K120	location reached at [CET]		10:12	10:27
	tide in Zeebrugge [m LAT]		1.52	1.58
Kwintebank-Scheur	min gross UKC to nautical bottom [%]	15.00	11.77	12.07
	min gross UKC to nautical bottom [m]	2.32	1.82	1.87
	point on trajectory		200	500
Scheur_West	min gross UKC to nautical bottom [%]	15.00	12.96	13.95
	min gross UKC to nautical bottom [m]	2.32	2.01	2.16
	point on trajectory		110	110
Pas_van_het_Zand	min gross UKC to nautical bottom [%]	12.50	14.12	15.07
	min gross UKC to nautical bottom [m]	1.94	2.19	2.34
	point on trajectory		7	7
	min gross UKC to top mud [%]	-7.00	14.12	15.07
	min gross UKC to top mud [m]	-1.08	2.19	2.34
	point on trajectory		7	7
Zeebrugge_Ingang	min gross UKC to nautical bottom [%]	12.50	14.84	15.61
	min gross UKC to nautical bottom [m]	1.94	2.30	2.42
	point on trajectory		0	0
	min gross UKC to top mud [%]	-7.00	14.84	15.61
	min gross UKC to top mud [m]	-1.08	2.30	2.42
	point on trajectory		0	0
	max current speed [knts]	2.00	1.41	1.31
	point on trajectory		0	0
Zeebrugge	min gross UKC to nautical bottom [%]	10.00	10.86	11.29
	min gross UKC to nautical bottom [m]	1.55	1.68	1.75
	point on trajectory		600	600
	min gross UKC to top mud [%]	-7.00	-7.21	-6.40
	min gross UKC to top mud [m]	-1.08	-1.12	-0.99
	point on trajectory		601	610
Zeebrugge_Kaai	min gross UKC to nautical bottom [%]	10.00	11.29	11.67
	min gross UKC to nautical bottom [m]	1.55	1.75	1.81
	point on trajectory		615	615
	min gross UKC to top mud [%]	-7.00	-6.77	-6.40
	min gross UKC to top mud [m]	-1.08	-1.05	-0.99
	point on trajectory		615	615
probability of bottom touch		1.00E-2	1.00E0	1.00E0

Figure 2. ProToel output file, showing waypoints and criteria as a function of departure time.

directly in ProToel and exported as a report in pdf format. An example is shown in Figure 2.

2.3 *Background information*

The ship data bank consists of squat and dynamic response data on a large number of slender and full hull forms, see Figure 3. The content of this databank is based on seakeeping tests carried out with five ship models in the *Towing tank for manoeuvres in shallow water (co-operation Flanders Hydraulics Research – Ghent University)* in Antwerp and additional numerical calculations with the 2D strip method *Seaway* and the 3D BEM *Aqua+*. The database covers a large number of draft – water depth combinations, and also contains data for a variation of metacentric heights.

Squat data can be directly obtained from the database by interpolation; for container vessels, the sinkage fore and aft can also be calculated by means of model test based empiric formulae that also take account of the lateral channel dimensions (Eloot et al, 2008).

The probability of bottom touch is calculated in a way that is customary for seakeeping problems, and

Beam [m]	Length over all [m] 180.0 - 199.9	200.0 - 219.9	220.0 - 239.9	240.0 - 259.9	260.0 - 279.9	290.0 - 299.9	300.0 - 319.9	320.0 - 339.9	340.0 - 359.9	360.0 - 379.9	380.0 - 399.9	400.0 - 419.9
30.0 - 32.9	G100	F100		D080								
33.0 - 35.9	G105	F105	F110		D085							
36.0 - 38.9	G110	G115	F115	F120	D090	D095						
39.0 - 41.9		G120	G125		F130	W072	D100					
42.0 - 44.9					E080	F140	W078	D105	D110			
45.0 - 47.9					E085	E090	W080	W085	D115	D118		
48.0 - 50.9							E095		W090	D120	D125	
51.0 - 53.9								E100		W095		
54.0 - 56.9											W100	

Source Containership / Source Bulkcarrier / Containership / Bulkcarrier

Figure 3. Combinations of ship length and beam covered by the database. The code refers to ship model (container carriers D, F, W; bulk carriers/tankers E, G) and scale factor (%).

which is based on a Rayleigh distribution of peak-to-peak values of responses of a ship to irregular waves. However, the probability calculation also accounts for a number of additional uncertainties. Due to the uncertainty of the bottom level, the still water draft, the tidal level, the squat estimation, the net UKC is not exactly known; for this reason, a standard deviation on this value is taken into account. Other types of uncertainty that are taken into consideration concern the quality of wave climate predictions, errors on response amplitude operators, effects of unknown parameters

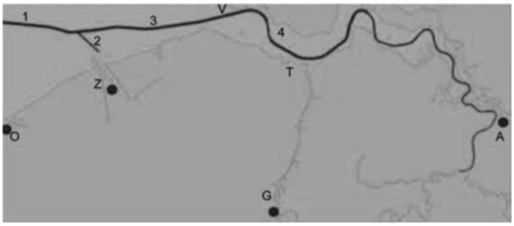


Figure 4. Access channels: 1: Scheur West, 2: Pas van het Zand, 3: Scheur East, 4: West Scheldt. Harbours: A: Antwerp/Antwerpen (B), G: Ghent/Gent (B), O: Ostend/Oostende (B), T: Terneuzen (NL), V: Flushing/Vlissingen (NL), Z: Zeebrugge (www.maritiemetoegang.be).

such as weight distributions and initial stability; the effect of such deviations is accounted for by introducing a standard deviation on the significant wave height.

3 APPLICATIONS

3.1 *Use of ProToel as a short term planning tool for shipping traffic to Zeebrugge*

3.1.1 *Criteria*

Presently deep-drafted ships arriving at or departing from Zeebrugge need to take account of following tidal restrictions (see Figure 4):

– in the *Scheur West* and *Pas van het Zand* channels, a gross UKC of at least 15% and 12.5% of draft, respectively, is required;
– in the outer harbour of Zeebrugge, i.e. within the breakwaters, the minimum gross UKC is reduced to 10%;
– in areas subject to sedimentation where the bottom of the navigation areas is covered with fluid mud, a penetration of 7% of draft in the mud layer is considered as acceptable in case sufficient tug assistance is available;
– passage of the breakwaters is subject to a current window limited by a value for the cross current of 2 knots.

For LNG-carriers, however, stricter criteria are maintained. The required UKC in the sea channels *Scheur West* and *Pas van het Zand* is increased to 20% of draft, and to 15% in the harbour area, while the acceptable cross current at the breakwaters is reduced to 1.5 knots.

According to a probabilistic approach, a tidal window should be determined in such a way that the probability of undesired phenomena – such as bottom touch – does not exceed a selected value. More important than the probability, however, is the risk, defined as the probability of occurrence multiplied by the financial and impact consequences. The latter depend on the channel bed (rock, sand, mud, ...), the type of vessel (tanker, general cargo, container, ...) and environmental sensitivity of the area. Considerations on acceptable risk and probability have been formulated by Savenije (1996), PIANC (1997) and others, and is usually related to an acceptable number of groundings during the lifetime of a channel. The acceptable overall probability of bottom touch is of the order of magnitude of 10^{-4}, while 10^{-2} may be considered as a maximum value for any ship transit.

Examples

As a (fictitious, but realistic) example, the results of ProToel are given for a container carrier (W100) with a length of 397.7 m, a beam of 56.4 m and a draft of 15.5 m departing from and arriving at the harbour of Zeebrugge in favourable wave conditions (significant wave height 0.9 m). The speed over ground is assumed to be 12 knots in the *Scheur West* channel, 10 knots in the *Pas van het Zand*, and 4 knots in the harbour area. Following a deterministic approach based on gross UKC, the tidal window for the departing ship (Figure 5) opens at 11:30 and closes at 17:30; however, between 13:30 and 15:45 no traffic is possible due to the tidal currents. From a probabilistic point of view, the probability of bottom touch is acceptable between 9:15 and 19:30, but the limiting criterion will be the penetration in the mud layer, which only takes acceptable values between 11:15 and 19:15. While the effect on the opening time of the tidal window is only marginal, the departure time can be postponed by 1.75 hours if a reduced gross UKC were accepted and a probabilistic approach were followed in this particular case. For the arriving ship (Figure 6), no advantage is obtained by introducing a probabilistic criterion in this particular case: the opening time of the window remains unchanged, while the closing time is determined by the acceptable penetration into the fluid mud layer. Also here, the tidal window is interrupted due to exceedance of the allowable cross current.

3.1.2 *Present status*

Actually (January 2009) *ProToel* can be used within the intranet of the Department of Mobility and Public Works of the Flemish Government. Forecasts for waves, tidal elevations and tidal currents are updated continuously by the Flemish Hydrography on the server of Flanders Hydraulics Research. In a next phase, the program will be validated and the probabilistic approach will be evaluated.

3.2 *Use of ProToel for long-term accessibility predictions*

In order to perform a long term accessibility analysis with *ProToel*, the program was extended to allow the execution of batch computations. In this way, the length of tidal windows can be calculated for all tidal cycles within a longer period, e.g. a year. For such a long term prediction, only astronomical tide data can be used, so that only deterministic criteria based on gross UKC can be applied for determining the tidal windows. For the statistical post-processing of the resulting tidal windows, additional tools have been developed.

location		limit	9:00	9:15	9:30	9:45	10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00
Zeebrugge_Kaai	min gross UKC to nautical bottom [%]	10	4.85	4.82	5.29	5.8	7.23	8.04	9.51	10.06	10.89	11.29	12.29	12.83	13.93
	min gross UKC to top mud [%]	-7	-13.21	-13.24	-12.78	-12.27	-10.84	-10.03	-8.56	-8	-7.17	-6.77	-5.78	-5.23	-4.14
Zeebrugge	min gross UKC to nautical bottom [%]	10	4.82	4.82	5.29	5.8	7.23	8.04	9.51	10.06	10.89	11.29	12.29	12.83	13.93
	min gross UKC to top mud [%]	-7	-13.24	-13.24	-12.78	-12.27	-10.84	-10.03	-8.56	-8	-7.17	-6.77	-5.78	-5.23	-4.14
Zeebrugge_Ingang	min gross UKC to nautical bottom [%]	12.5	4.82	5.29	5.8	7.23	8.04	9.51	10.06	10.89	11.29	12.29	12.83	13.93	14.51
	min gross UKC to top mud [%]	-7	-6.79	-6.33	-5.82	-4.38	-3.57	-2.11	-1.55	-0.72	-0.32	0.67	1.22	2.31	2.9
	max current speed [knts]	2	1.88	1.82	1.79	1.71	1.67	1.55	1.49	1.37	1.3	1.13	1.01	0.77	0.66
Pas_van_het_Zand	min gross UKC to nautical bottom [%]	12.5	9.36	9.8	10.61	11.75	12.96	14.02	14.83	15.41	16.02	16.8	17.62	18.44	19.33
	min gross UKC to top mud [%]	-7	9.36	9.8	10.61	11.75	12.96	14.02	14.83	15.41	16.02	16.8	17.62	18.44	19.33
Scheur_West	min gross UKC to nautical bottom [%]	15	10.37	11.27	12.34	13.4	14.34	15.09	15.77	16.47	17.23	18.05	18.88	19.81	20.86
Kwintebank-Scheur	min gross UKC to nautical bottom [%]	15	11.27	11.97	13.4	14.04	15.09	15.55	16.47	16.97	18.05	18.6	19.81	20.5	22.15
probability of bottom touch		1.0E-02	1.4E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

12:00	12:15	12:30	12:45	13:00	13:15	13:30	13:45	14:00	14:15	14:30	14:45	15:00	15:15	15:30	15:45	16:00	16:15	16:30
13.93	14.51	15.81	16.58	18.45	19.57	22.32	23.93	27.38	28.97	31.35	32.04	32.44	32.29	31.64	31.24	30.26	29.65	28.25
-4.14	-3.55	-2.25	-1.49	0.38	1.51	4.25	5.87	9.32	10.91	13.29	13.98	14.38	14.22	13.58	13.17	12.2	11.59	10.18
13.93	14.51	15.81	16.58	18.45	19.57	22.32	23.93	27.38	28.97	31.35	32.04	32.29	32	31.24	30.78	29.65	28.97	27.49
-4.14	-3.55	-2.25	-1.49	0.38	1.51	4.25	5.87	9.32	10.91	13.29	13.98	14.22	13.94	13.17	12.72	11.59	10.91	9.43
14.51	15.81	16.58	18.45	19.57	22.32	23.93	27.38	28.97	31.35	32.04	32.44	32.29	31.64	31.24	30.26	29.65	28.25	27.49
2.9	4.2	4.96	6.84	7.96	10.71	12.32	15.77	17.36	19.74	20.43	20.83	20.67	20.03	19.63	18.65	18.04	16.63	15.88
0.66	0.49	0.48	0.72	0.97	1.68	2.1	2.89	3.18	3.45	3.44	3.17	2.98	2.58	2.4	2.1	1.98	1.76	1.65
19.33	20.33	21.5	22.96	24.69	26.84	29.29	31.9	34.23	35.87	36.61	36.44	36.12	35.31	34.8	33.55	32.84	31.37	30.63
19.33	20.33	21.5	22.96	24.69	26.84	29.29	31.9	34.23	35.87	36.61	36.44	36.12	35.31	34.8	33.55	32.84	31.37	30.63
20.86	22.15	23.67	25.58	27.77	30.18	32.51	34.37	35.67	36.21	36.06	35.6	35.02	34.28	33.4	32.35	31.25	30.08	28.88
22.15	23.14	25.58	27.02	30.18	31.75	34.37	34.63	34.15	33.01	32.36	30.91	30.1	28.37	27.47	25.63	24.69	22.82	21.86
0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

16:30	16:45	17:00	17:15	17:30	17:45	18:00	18:15	18:30	18:45	19:00	19:15	19:30	19:45	20:00	20:15	20:30	20:45	21:00
28.25	27.49	25.95	25.16	23.48	22.62	20.85	19.86	17.59	16.34	13.91	12.79	10.77	9.82	8.08	7.3	5.94	5.35	4.33
10.18	9.43	7.89	7.09	5.42	4.56	2.78	1.8	-0.47	-1.72	-4.16	-5.27	-7.3	-8.24	-9.99	-10.76	-12.13	-12.72	-13.73
27.49	26.73	25.16	24.34	22.62	21.75	19.86	18.78	16.34	15.1	12.79	11.75	9.82	8.92	7.3	6.59	5.35	4.81	3.91
9.43	8.66	7.09	6.27	4.56	3.69	1.8	0.71	-1.72	-2.97	-5.27	-6.31	-8.24	-9.14	-10.76	-11.48	-12.72	-13.25	-14.16
27.49	25.95	25.16	23.48	22.62	20.85	19.86	17.59	16.34	13.91	12.79	10.77	9.82	8.08	7.3	5.94	5.35	4.33	3.91
15.88	14.34	13.55	11.87	11.01	9.23	8.25	5.98	4.73	2.29	1.18	-0.85	-1.79	-3.54	-4.31	-5.68	-6.27	-7.28	-7.71
1.65	1.41	1.27	0.94	0.76	0.57	0.61	0.8	0.9	1.09	1.2	1.41	1.49	1.62	1.66	1.71	1.72	1.75	1.75
30.63	29.08	28.28	26.62	25.72	23.63	22.45	20.01	18.84	16.69	15.69	13.85	13	11.5	10.85	9.72	9.24	8.46	8.07
30.63	29.08	28.28	26.62	25.72	23.63	22.45	20.01	18.84	16.69	15.69	13.85	13	11.5	10.85	9.72	9.24	8.46	8.07
28.88	27.64	26.36	25.02	23.56	21.88	20.09	18.34	16.71	15.23	13.85	12.61	11.49	10.51	9.65	8.94	8.35	8.01	7.92
21.86	19.93	18.93	16.91	15.95	14.21	13.43	12.03	11.4	10.31	9.87	9.25	9.1	8.94	8.22	8.01	8.01	7.93	8.01
0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.0E-11	1.6E-14	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00

Figure 5. ProToel results for a container vessel departing from Zeebrugge (fictitious example).

location		limit	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00	10:15	10:30	10:45	11:00	11:15
Kwintebank-Scheur	min gross UKC to nautical bottom [%]	15	11.77	12.07	12.71	13.16	14.23	14.81	15.98	16.59	17.79	18.37	19.49	20.07	21.35
Scheur_West	min gross UKC to nautical bottom [%]	15	12.96	13.95	14.85	15.63	16.28	16.93	17.64	18.41	19.26	20.16	21.23	22.5	24.08
Pas_van_het_Zand	min gross UKC to nautical bottom [%]	12.5	14.12	15.07	15.83	16.42	16.99	17.67	18.43	19.25	20.13	21.15	22.34	23.84	25.61
	min gross UKC to top mud [%]	-7	14.12	15.07	15.83	16.42	16.99	17.67	18.43	19.25	20.13	21.15	22.34	23.84	25.61
Zeebrugge_Ingang	min gross UKC to nautical bottom [%]	12.5	14.84	15.61	16.18	16.75	17.49	18.29	19.13	20.03	21.08	22.34	23.92	25.8	28.04
	min gross UKC to top mud [%]	-7	14.84	15.61	16.18	16.75	17.49	18.29	19.13	20.03	21.08	22.34	23.92	25.8	28.04
	max current speed [knts]	2	1.41	1.31	1.22	1.12	0.98	0.82	0.64	0.49	0.45	0.58	0.92	1.4	1.99
Zeebrugge	min gross UKC to nautical bottom [%]	10	10.86	11.29	12.04	12.47	13.5	14.05	15.2	15.85	17.38	18.33	20.63	22.01	25.12
	min gross UKC to top mud [%]	-7	-7.21	-6.4	-6.02	-5.09	-4.56	-3.45	-2.86	-1.5	-0.68	1.34	2.57	5.46	7.06
Zeebrugge_Kaai	min gross UKC to nautical bottom [%]	10	11.29	11.67	12.47	12.97	14.05	14.61	15.85	16.56	18.33	19.41	22.01	23.52	26.73
	min gross UKC to top mud [%]	-7	-6.77	-6.4	-5.59	-5.09	-4.02	-3.45	-2.22	-1.5	0.26	1.34	3.95	5.46	8.66
probability of bottom touch		1.0E-02	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

11:15	11:30	11:45	12:00	12:15	12:30	12:45	13:00	13:15	13:30	13:45	14:00	14:15	14:30	14:45	15:00	15:15	15:30	15:45
21.35	22.08	23.78	24.79	27.12	28.43	31.09	32.31	34.22	34.85	35	34.62	33.63	33.02	31.63	30.89	29.35	28.55	26.9
24.08	25.96	28.13	30.39	32.48	34.19	35.23	35.72	35.56	35	34.62	33.63	33.02	31.63	30.89	29.35	28.55	26.9	26.04
25.61	27.74	30.05	32.31	34.24	35.49	36.15	36.06	35.54	35.13	34.12	33.48	32.04	31.28	29.74	28.94	27.26	26.4	24.55
25.61	27.74	30.05	32.31	34.24	35.49	36.15	36.06	35.54	35.13	34.12	33.48	32.04	31.28	29.74	28.94	27.26	26.4	24.55
28.04	30.45	32.76	34.68	35.85	36.41	36.36	36.03	35.54	34.93	34.12	33.14	32.04	30.9	29.74	28.53	27.26	25.96	24.55
28.04	30.45	32.76	34.68	35.85	36.41	36.36	36.03	35.54	34.93	34.12	33.14	32.04	30.9	29.74	28.53	27.26	25.96	24.55
1.99	2.58	3.04	3.33	3.35	3.21	2.96	2.69	2.43	2.21	2.03	1.86	1.7	1.52	1.31	1.07	0.82	0.6	0.58
25.12	26.73	29.56	30.61	31.75	31.85	31.36	31.02	30.16	29.6	28.26	27.52	26	25.22	23.59	22.75	20.99	20.03	17.86
7.06	10.18	11.5	13.27	13.68	13.78	13.29	12.95	12.09	11.54	10.2	9.45	7.93	7.15	5.53	4.68	2.92	1.97	-0.2
26.73	28.25	30.61	31.33	31.91	31.85	31.36	31.02	30.16	29.6	28.26	27.52	26	25.22	23.59	22.75	20.99	20.03	17.86
8.66	10.18	12.55	13.27	13.84	13.78	13.29	12.95	12.09	11.54	10.2	9.45	7.93	7.15	5.53	4.68	2.92	1.97	-0.2
0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

15:45	16:00	16:15	16:30	16:45	17:00	17:15	17:30	17:45	18:00	18:15	18:30	18:45	19:00	19:15	19:30	19:45	20:00	20:15
26.9	26.04	24.22	23.22	21.01	19.85	17.63	16.59	14.69	13.81	12.21	11.5	10.23	9.68	8.75	8.37	7.9	7.85	7.85
26.04	24.22	23.22	21.01	19.85	17.63	16.59	14.69	13.81	12.21	11.5	10.23	9.68	8.75	8.37	7.9	7.84	7.86	8.23
24.55	23.51	21.19	19.98	17.71	16.67	14.74	13.83	12.19	11.46	10.18	9.62	8.65	8.25	7.7	7.59	7.72	8.28	8.95
24.55	23.51	21.19	19.98	17.71	16.67	14.74	13.83	12.19	11.46	10.18	9.62	8.65	8.25	7.7	7.59	7.72	8.28	8.95
24.55	22.96	21.19	19.39	17.71	16.17	14.74	13.39	12.19	11.11	10.18	9.35	8.65	8.07	7.7	7.58	7.89	8.59	9.69
24.55	22.96	21.19	19.39	17.71	16.17	14.74	13.39	12.19	11.11	10.18	9.35	8.65	8.07	7.7	7.58	7.89	8.59	9.69
0.58	0.7	0.83	0.97	1.12	1.28	1.42	1.53	1.61	1.66	1.69	1.71	1.72	1.72	1.7	1.69	1.66	1.64	1.6
17.86	16.67	14.3	13.19	11.17	10.22	8.47	7.68	6.27	5.66	4.6	4.14	3.41	3.18	3.06	3.14	3.81	4.43	6.01
-0.2	-1.39	-3.76	-4.87	-6.9	-7.85	-9.6	-10.39	-11.79	-12.4	-13.47	-13.93	-14.65	-14.88	-15	-14.69	-14.25	-12.89	-12.05
17.86	16.67	14.3	13.19	11.17	10.22	8.47	7.68	6.27	5.66	4.6	4.14	3.41	3.18	3.14	3.38	4.43	5.18	6.85
-0.2	-1.39	-3.76	-4.87	-6.9	-7.85	-9.6	-10.39	-11.79	-12.4	-13.47	-13.93	-14.65	-14.88	-14.93	-14.69	-13.64	-12.89	-11.21
0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00

Figure 6. ProToel results for a container vessel arriving at Zeebrugge (fictitious example).

This type of application was performed for a container carrier arriving at and departing from the harbour of Antwerp. An example of the output is given in Figure 7, and can be interpreted as follows: for both the arriving and departing ships with the considered draft values, a tidal window of at least 60 minutes is expected in more than 92% of the cases. It should be mentioned that in the example the arriving ship has a larger draft than the departing ship.

The computations appeared to be in good agreement with an existing analysis, but also revealed that the results may be very sensitive to the detailed depth profile and the assumptions used for interpolation of the tidal curves along the trajectory.

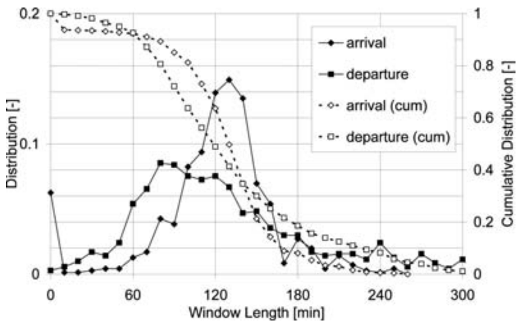


Figure 7. Distribution of length of tidal windows for container vessels arriving at/departing from Antwerp with given drafts (different for arrival and departure, values not communicated), based on a one-year period. The cumulative distribution shows the fraction of the tides offering a window with a length of at least the abscissa value. Note that a percentage of tides (especially for arriving vessels) does not result into a tidal window for the given draft, yielding a nonzero distribution value for a window length equal to zero.

4 TOWARDS A GENERALISED PROBABILISTIC METHODOLOGY

4.1 *Introduction*

Although the present tool can be applied to a wide range of access channels, the development of a general methodology for a probabilistic approach requires a number of extensions.

In the first place, squat not only depends on the ship characteristics and speed through water, but is also affected by the channel characteristics (water depth, lateral limitations), the proximity of banks and interaction with meeting and overtaking or overtaken ships.

Furthermore, the probability of bottom touch does not only depend on squat and the response to the local wave climate, but other effects may be of importance as well (e.g. wind, heel in bends). In some cases, even the basic principle for determining the probability of undesired events might have to be reconsidered. This is especially the case if the response to waves is not the main cause of bottom touch.

Finally, it should always be born in mind that not only contact with the bottom due to vertical motions should be taken into account, but that all undesired events (groundings, collisions with fixed structures or with other ships) are of importance in order to assess the total safety of shipping traffic.

4.2 *Practical case: access to Antwerp for large container vessels*

The importance of additional effects on squat can be illustrated by the results of real-time simulations that have been executed on the ship manoeuvring simulators of Flanders Hydraulics Research (SIM225 and SIM360+) to evaluate the accessibility of the West Scheldt for large containerships with a length over all of 366 – 380 – 400 m. Both simulators were coupled so that with two operating bridges the encounters are as realistic as possible.

During the simulations the sinkage fore and aft was calculated taking into account ship dependent parameters (draft, displacement, block coefficient, midship section area); environmental parameters (water depth, distance to banks); operational parameters (forward and lateral velocities and accelerations, yaw rate and acceleration, propeller rate) and other shipping traffic (draft of target ship, displacement of target ship, block coefficient of target ship, lateral distance between ships, longitudinal velocity of target ship) (Eloot et al. 2008).

As an example, Figure 8 shows a particular encounter of a departing containership (366 m × 48.8 m × 13.1 m) with a larger ship (400 m × 56.4 m × 14.5 m) in the bend of Bath on the river Scheldt (maximum flood current, wind SW 5Bf). The encounter occurred with a lateral distance equal to 56m and a relative speed through the water for both ships of approximate3ly 12 knots. The velocity parameters and sinkages of the downstream ship can be studied based on the graphs in Figure 8. The lowest obtained static UKC along the whole trajectory is approximately 50% while the maximum sinkage occurs at the stern with a maximum UKC reduction of approximately 10% of the ship's draft.

4.3 *Requirements*

At least the following investigations are required to develop a generalised probabilistic admittance policy for deep-drafted ships:

- Redefinition of the probability of bottom touch in navigation channels that are not exposed to wave action. The present method for calculating this probability is based on a Rayleigh distribution of the peak-to-peak values for the vertical motion of a number of critical points. Hence, the overall probability during a transit requires the availability of a value for the average encounter period, which cannot be defined in absence of waves. Therefore, there is a need for an alternative methodology resulting into a probability of bottom contact that is not merely dependent on the characteristics of the wave spectrum.
- Integration of the influence of wind on net UKC. This effect may be caused in several ways: the lateral force and yawing moment caused by non-longitudinal relative wind directions result into the occurrence of both heel, which directly reduces the UKC, and drift, which may lead to increased squat, but also to reduced speed.
- Integration of the effect of cross currents and waves on drift and, eventually, on squat;
- Integration of the effect of bends in the fairway, which may cause speed reduction, but also heel and increased squat due to yawing and drift.

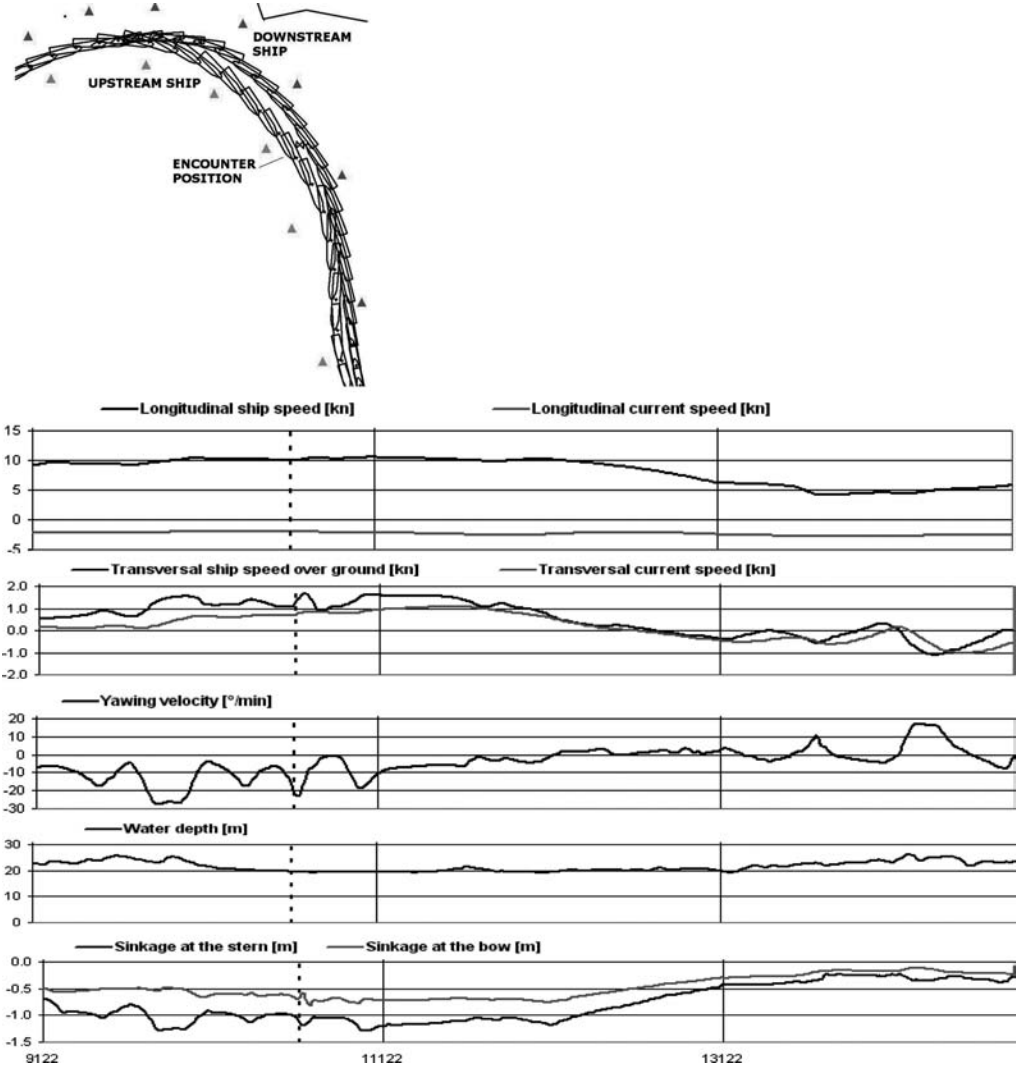


Figure 8. Real-time simulation of an encounter at the bend of Bath during flood tide: trajectories of both ships during the total manoeuvre and parameters of the ship sailing downstream with the encounter position indicated with a dashed vertical line.

– Integration of the effect of interaction with other shipping traffic, particularly on squat;
– Integration of the effect of interaction with banks, particularly on squat;
– Link with occurrence of other undesired effects.

5 CONCLUSIONS

A software tool for supporting operational and strategic decisions concerning accessibility of harbours for (deep-drafted) vessels subject to tidal windows has been presented. For short-term planning the tool has been implemented for the approach to the harbour of Zeebrugge, where multiple criteria (gross UKC, probability of bottom touch, keel penetration into fluid mud layers, cross currents) are of importance. An example is also given of a long-term statistical analysis of the length of tidal windows. Finally, requirements are formulated that have to be fulfilled to develop a generalised probabilistic admittance policy for deep-drafted ships.

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Chapter 6. Anti-collision

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6.1 Behaviour patterns in crossing situations

J. Kemp
Professor Emeritus, Arundel, UK

ABSTRACT: The January 2009 issue of the *Journal of Navigation* included a paper (John Wilde Crosbie 2009) entitled, "Revisiting the lessons of the early steering and sailing rules for an e-navigation age." Following a description of the development of the COLREGS from the early 19th century, he concluded that the current steering and sailing rules should be replaced by a single rule more suited to modern conditions. This might take the form of rule stating that a vessel taking action to avoid collision should not pass ahead of the other vessel.

Such a rule would require a radical change in the philosophy of collision avoidance at sea, and evidence is required that it would be both effective and acceptable by mariners. Radar simulator experiments, conducted by the author some years ago, in another context, suggest that this might be the case. An analysis of the experimental results and some conclusions are reported in this paper. The author believes that further trials, specifically designed to test the Crosbie proposals, would be desirable.

1 INTRODUCTION

A recent paper (John Wilde Crosbie, 2009) contained an examination of the development of the COLREGS from the early 19th century to the present day. This led to him to conclude that the current form of the COLREGS is over-complicated and unsuited to present day conditions. Also that they should be replaced by a much simpler convention based on proposals by Commander, later Vice-Admiral, P.H. Colomb of the UK Royal Navy in the late 1800s (Colomb, 1866, 1885). This is referred to in the following sections as the Colomb/Crosbie proposal, and some of its implications are considered in this paper.

A general rule to implement the Colomb/Crosbie proposals might state that a vessel taking action to avoid collision should not pass ahead of the other vessel. Either vessel in an encounter would be permitted to take appropriate action.

In a case where a vessel sees another crossing from her own starboard bow, an alteration of course to starboard to pass under the stern of the approaching ship would be appropriate action and similar to the usual action taken under the current rules. In the case of a ship which sees another crossing from her port bow, an alteration of course to port would be appropriate action under the Colomb/Crosbie convention but this would be quite different to the requirement to maintain course and speed under the current rules.

Clearly, there is a possibility in either of the above situations that, if each ship attempts to pass astern of the other, their actions might cancel and there would be a renewed risk of collision. However, for reasons which he explains in his paper, John Wilde Crosbie (JWC) believes that such conflicting actions would be rare and, if they should occur, they could easily be resolved.

JWC bases his conclusions on an analysis of COLREG developments and the views of commentators, particularly in the UK during the 19th century, when the COLREGS first became properly formalised. He provides no experimental evidence to support his arguments, but the present author is reminded of the results of some radar simulator trials he conducted some thirty years ago. These results have never been published but, since they shed light on the possible acceptability of JWC's conclusions, they are reported in the following sections of this paper.

2 EXPERIMENTAL DESIGN

In this section, two radar simulator experiments are described. In the first, each subject was presented with a situation in which a "target vessel" was approaching from the port bow of the subject's "own ship" (see fig. 1). The target vessel's course was at right angles to the own ship's course. The own ship's full speed was 15 knots, but it was initially set at half speed of 10 knots. Collision would occur after 33 minutes if the subject took no action.

The second experiment presented each subject with a similar situation except that the target ship was approaching from the own ship's starboard bow (see fig. 2).

In both cases, the collision avoidance action taken by the subjects could be allocated to one of three categories: Alteration of course to starboard, alteration of course to port, or change of speed only. These categories are abbreviated to "Stbd", "Port" and "Speed" respectively in the tables of section 3.

Most of the subjects were mariners with at least six years of watchkeeping experience. There was also

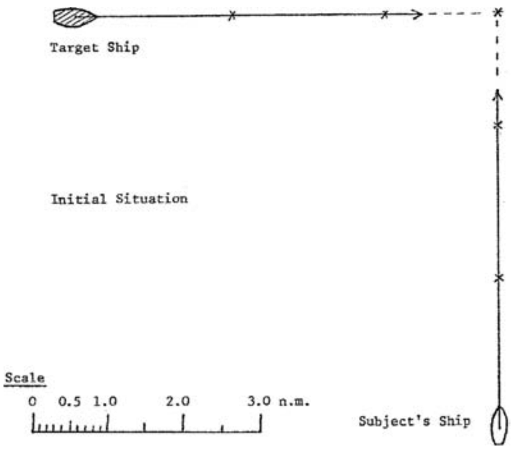

Figure 1. Experiment 1 Port bow approach.

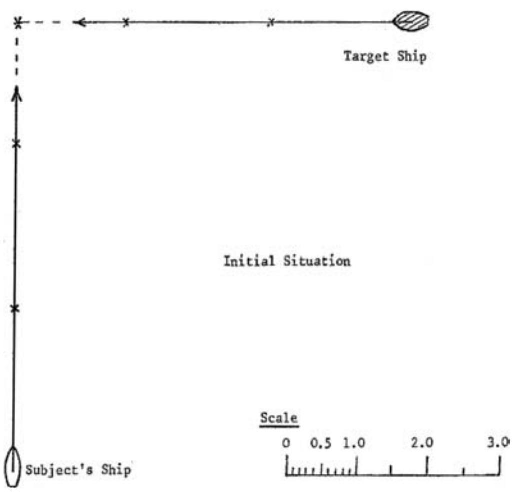

Figure 2. Experiment 2 Starboard bow approach.

a smaller "control group" of naïve subjects with no seagoing experience and no knowledge of the COLREGS. Separate analyses were conducted for the two experiments and for each of the experienced and naïve groups of subjects. That is, four analyses in all.

In every case, a χ^2 test was used to find whether there was evidence that subjects had significant preferences amongst the three categories of action defined above. The null hypothesis was an equal probability that the subjects would choose any of the three categories of action. The alternative hypothesis was that this would not be the case. A 0.05 level of significance was considered sufficient to reject the null hypothesis. The results are summarised in section 3, below.

3 ANALYSES

3.1 *Port bow approach, naïve subjects*

Of the 15 naïve subjects who were presented with the port bow situation, the numbers observed to take each of the three categories of action appear in the first row of table 1.

Table 1.

	Stbd.	Port.	Speed	Total
Observed (O)	2	10	3	15
Expected (E)	5	5	5	15
$(O-E)^2$	9	25	4	38

$$\chi^2 = (O\text{-}E)^2/E = 38/5 = 7.6$$

This is greater than $\chi^2(2, 0.05) = 5.99$. We therefore reject the null hypothesis and conclude there is significant evidence that the subjects prefer some manoeuvres rather than others. In this case, they clearly prefer alterations of course to port rather than alterations of course to starboard, and this provides some justification for describing an alteration of course to port as a "natural" manoeuvre in the given situation.

3.2 *Starboard bow approach, naïve subjects*

Of the 14 naïve subjects who were presented with the starboard bow situation, the numbers observed to take each of the three categories of action appear in the first row of table 2.

Table 2.

	Stbd.	Port.	Speed	Total
Observed (O)	9	0	5	14
Expected (E)	4.7	4.7	4.7	14
$(O-E)^2$	18.5	22.1	0.1	40.7

$$\chi^2 = (O\text{-}E)^2/E = 40.7/4.7 = 8.7.$$

This is greater than $\chi^2(2, 0.05) = 5.99$. We therefore reject the null hypothesis and conclude that there is significant evidence that the subjects prefer some manoeuvres rather than others. In this case, alterations of course to starboard are preferred to alterations of course to port. As before, this provides some justification for describing alterations of course to starboard as "natural" manoeuvres in the given situation.

3.3 *Port bow approach, experienced subjects*

Of the 23 experienced subjects who were presented with the port-bow situation, the numbers observed to take each of the three categories of action appear in the first row of table 3.

$$\chi^2 = (O\text{-}E)^2/E = 4.7/7.7 = 0.61$$

This is less than $\chi^2(2, 0.05) = 5.99$. We therefore accept the null hypothesis and conclude that

Table 3.

	Stbd.	Port.	Speed	Total
Observed (O)	8	9	6	23
Expected (E)	7.7	7.7	7.7	23
$(O-E)^2$	0.1	1.7	2.9	4.7

Table 4.

	Stbd.	Port.	Speed	Total
Observed (O)	23	0	1	24
Expected (E)	8	8	8	24
$(O-E)^2$	225	64	49	338

experienced subjects do not have a preference among the three categories of action. In particular, there is no evidence to suggest that they prefer alterations of course to starboard rather than alterations of course to port in the given situation.

3.4 *Starboard bow approach, experienced subjects*

Of the 24 experienced subjects who were presented with the starboard bow situation, the numbers observed to take each of the three categories of action appear in the first row of table 4.

$$\chi^2 = (O\text{-}E)^2/E = 338/8 = 42.2$$

This is greater than $\chi^2\,(2, 0.05) = 5.99$. We therefore reject the null hypothesis and conclude that there is significant evidence to suggest that the experienced subjects have a preference among the three categories of action in this type of encounter. It is clearly a strong preference for alterations of course to starboard.

4 INITIAL RESULTS

4.1 *"Natural" manoeuvres*

In sections 3.1 and 3.2, naïve subjects, with no knowledge of the COLREGS, altered course to port for a threat on their port bow and altered course to starboard for a threat from the starboard bow. These are consistent responses, since one situation is the mirror image of the other. Also, since it was taken by the majority of naïve subjects, we may consider these to be "natural" actions rather than responses to a set of rules.

4.2 *COLREGS comparison, port bow threat*

In the case of a vessel approaching from a subject's starboard bow, the natural action is in accordance with the COLREGS. In the case of a vessel approaching from a subject's port bow, the natural action is entirely different to that prescribed by the COLREGS. Rule 17, somewhat illogically, requires the subject's vessel, (i) to keep her course and speed and (ii) if she does take action, not to alter course to port. Rule 19, which applies in restricted visibility, states that an alteration of course to port should be avoided for an approaching vessel forward of the beam.

Experienced subjects, faced with a threat from the port bow, were equally divided between alterations of course to starboard (in accordance with the COLREGS) and alterations of course to port (in accordance with natural action and with the Colomb/Crosbie convention).

4.3 *COLREGS comparison, starboard bow*

Moving on to the results for the situation where the target vessel is approaching from a subject's starboard bow, we find that both naïve and experienced subjects take similar action. That is, alterations of course to starboard.

In this situation, an alteration of course to starboard was the natural action of the naïve subjects and it is also permitted under rule 15 of the COLREGS and under rule 19 when, in restricted visibility, the approaching vessel is detected by radar. With no conflicting considerations involved, all the experienced subjects (except one who decreased speed) altered course to starboard. In doing so, they complied with both the COLREGS and the Colomb/Crosbie recommendations.

5 THE EFFECT OF EXPERIENCE

5.1 *Conflict with the COLREGS*

The experiments described in section 3 above were not, originally, designed to test the Colomb/Crosbie proposals. However, as discussed in section 4, they shed some light on how readily those proposals might be accepted by mariners. The results show that a considerable proportion of experienced mariners appear willing to take action as implied by the Colomb/Crosbie convention, even in cases where such action is clearly opposed to action prescribed by the COLREGS. Clearly, this proportion could be expected to increase if the present COLREGS were repealed.

5.2 *Rapid versus slow disengagement*

In many collision encounters, the navigator has a choice between an action which resolves the situation quickly but which initially involves a more rapid approach to the other vessel, and an action which gives a more prolonged disengagement and which initially decreases the rate of approach to the other vessel.

In the case of a threat from the starboard bow (as in fig. 2) a manoeuvre for rapid disengagement corresponds with both the COLREGS and "natural" action, – that is an alteration of course to starboard. As the results reported in section 3.4 show, practically all experienced mariners take this action.

In the case of a threat from the port bow (as in fig. 1) a manoeuvre to achieve rapid disengagement, – that is an alteration of course to port, is contrary to the COLREGS. As the results reported in section 3.3 show, experienced mariners are equally divided as to which way they alter course.

5.3 *Rational for a hypothesis*

In the port bow case of fig. 1, one choice is of a safe but time consuming action of an alteration of course to starboard or a reduction of speed. The other choice is an apparently riskier, but more efficient, alteration of course to port or an increase in speed. About half of the experienced subjects took the latter choice although it was clearly not sanctioned by the COLREGS so it is of interest to speculate as to why this should be the case. The tendency of many experienced subjects to take risky action may be explained in terms of behaviour theory as developed by B F Skinner (Skinner, 1953). This suggests that an alteration of course to port, although contrary to the COLREGS, leads to a rapid disengagement and relief from anxiety so it is reinforced on every occasion that it is successful. An alteration of course to starboard may break the initial collision situation but it leads to a prolongation of the encounter and therefore a continued period of anxiety until disengagement is finally achieved and the own ship can resume its original course. If this suggestion is correct, then alterations of course to port for a threat on the port bow should be more common amongst the more experienced mariners. This was taken as a working hypothesis for a supplementary analysis.

6 A SUPPLEMENTARY ANALYSIS

6.1 *Purpose*

This analysis was conducted to test the above hypothesis by investigating a possible relationship between the actions taken by mariners and their respective lengths of experience. For this purpose, their actions were divided into two groups according to whether they were in conformity with the restricted visibility COLREGS (rule following) or in conflict with the COLREGS (rule averse).

In the port bow approach, this corresponded to a choice between a safe manoeuvre that would prolong the encounter (alteration of course to starboard or reduce speed) and a riskier manoeuvre that would resolve the encounter quickly (alteration of course to port or an increase in speed). In table 5, the type of manoeuvre chosen is tabulated against the length of experience of 23 subjects. A Rule–following alteration of course to starboard or reduction of speed is coded as “R”. A rule-Averse alteration of course to port or increase in speed is coded as “A”.

6.2 *Analysis*

To analyse table 5, we note that, because of wastage amongst younger mariners, experience amongst a random group is likely to be highly skewed rather than normally distributed. Also the effect of experience on a mariner’s behaviour is unlikely to be linear so that

Table 5. Experience v. Manoeuvre Class.

	Experience Years & months	Manoeuvre class
1	6–6	R
2	6–9	R
3	7–6	R
4	9–1	R
5	9–5	R
6	9–6	A
7	9–9	R
8	10–9	R
9	11–4	A
10	11–8	R
11	12–3	A
12	12–4	A
13	12–8	R
14	13–0	A
15	14–1	A
16	14–7	A
17	14–8	A
18	18–3	A
19	18–6	R
20	19–0	R
21	26–5	A
22	28–2	A
23	29-0	A

means and standard deviations, calculated arithmetically, may not be reliable statistics in the context of this analysis.

Of the available non-parametric methods of analysis, the Mann-Whitney U test seems appropriate because the test depends upon ranking but not on an interval scale and it does not assume a particular distribution

From table 5, we note that 11 subjects took actions of class “A” and 12 subjects took actions of class “B”. The value of the Mann-Whitney U statistic is calculated as 26. This is less than 28, the value for a one tailed test at a 1% level of significance. We therefore reject the null hypothesis and accept the alternative hypothesis that, as experience increases, mariners are more likely to choose actions that resolve an encounter quickly. Typically, they are more ready to alter course to port for a threat from the port bow.

7 DISCUSSION

A full investigation of the Crosbie/Colomb proposal would require consideration of many factors. This paper simply describes two radar simulator experiments which suggest that an investigation is worth while.

In the case of a threat approaching from a broad angle on the starboard bow (fig. 2) an alteration of course to starboard was the favoured manoeuvre for both experienced and naïve subjects. This was compatible with both the Colomb/Crosbie proposal and the current COLREGS in both clear weather and restricted visibility.

In the case of a threat approaching from a broad angle on the port bow (fig. 1) naïve subjects favoured an alteration of course to port. Experienced subjects were equally divided amongst an alteration of course to port, an alteration of course to starboard and an alteration of speed. This might be thought a surprising result in that one would expect experienced mariners to all comply with rule 19 or rule 17 of the COLREGS and avoid an alteration of course to port. This result gives some support to the Colomb/Crosbie proposal, which would allow such an action.

It is also of interest that, in the same situation, a manoeuvre, such as an alteration of course to port, which leads to a rapid disengagement becomes more acceptable as a mariner's experience increases.

Returning to the above observation that some experienced mariners chose to disregard Rule 17 or 19 we should not, perhaps, be too surprised since a number of commentators have, over the years, noted that mariners take a relaxed attitude to following the COLREGS. For example, Syms (2003) analysed the results of a Nautical Institute survey into mariners' interpretations of Rule 19 in a hypothetical collision situation and concluded that, *Fewer than a quarter picked the correct action for both vessels to alter course to starboard*. And, Salinas (2006) found that, in relation to Rule 19d, ….. *it has been clearly proved there exists complete disagreement between what the COLREGS state and what seafarers really do.*

8 CONCLUSIONS

At this stage, it should be made clear that the author is not taking a position for or against the Colomb/Crosbie proposal. He is simply presenting some evidence that suggests that an action taken in accordance with that proposal would be acceptable to mariners in two particular situations.

The author does recommend that the Colomb/Crosbie proposal is worth further investigation and that further tests, using a simulator with a daylight display, should be conducted with the specific purpose of investigating the Colomb/Crosbie proposal.

The author also notes that adoption of the Colomb/Crosbie proposal would create such radical changes in the Rules for Avoiding Collisions at Sea that it might be impossible ever to achieve international agreement. That might be shame.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

6.2
Method of safe returning of the vessel to planned route after deviation from collision

M. Tsymbal & I. Urbansky
Odessa National Maritime Academy, Odessa, Ukraine

ABSTRACT: Flexible strategies for collision avoidance, presented at TransNav 2007, were examined using computer program for its correctness in different situations of ships interaction. It was determined, that on short distance the risk of collision can arise again when the vessel returning to the planned route after deviation from collision. For controlling ship's safe returning, the mathematical model was developed. This model describes the analytical dependence of the rate of changing relative course with respect to rates of turning of the vessels and its initial relative position. This method can be used in automatic systems for controlling the safe returning of the vessel to the planned route.

1 INTRODUCTION

Flexible strategies for collision avoidance, take into account the presence of dangerous and obstacle vessels, hazards for navigation and the Colreg requirements. The strategy of collision avoidance depends on the realized range of mutual duties, relative position of vessel and target and, correlation of their speeds. In general strategy of deviation foresees transfer the current position of the vessel from subset of dangerous positions to subset of safe positions, calculation the deviation course and then returning to the planned route by a course tangent to the circle of the assigned CPA (Tsymbal 2006, 2007, 2008).

During modeling the flexible strategies on computer, it was determined, that on short distances the risk of collision can arise again when the vessel returning to the planned route after deviation from collision.

The paper presents the method for calculating the parameters for ship manoeuvring, when returning to the planned route after deviation from collision.

2 MATHEMATICAL MODEL

2.1 *Three types of returning trajectories*

The detailed analysis, shows that for safe returning of the vessel on the planned route in default of coordination between the ship and target it is necessary the initial situation G to identify with one of three subsets Mn1, Mn2 or Mn3, each of which determines the type of trajectory for returning the ship and mathematical model for calculation the parameters of manoeuvre.

The first subset M_{n1} includes safe situations G, when are assured increase the distance L_t between the vessels and target, i.e. $dL_t/dt > 0$. Second subset M_{n2} includes situations, when distance between the ship and target reduces, i.e. $dL_t/dt < 0$. And, finally, the third subset of situations M_{n3} includes those situations, for which it is possible increasing or reducing the distance L_t.

For identification the type of initial situation G it is necessary to calculate the initial relative course K_{oto} and rate of its change ω_{otb}.

2.2 *Calculation of relative course and rate of its change*

The initial relative course K_{oto} means the relative course of the ship's deviation. Its calculation is produced on the parameters of motion of the vessel and target by expression:

$$K_{oto} = \arcsin[\frac{V_v \sin K_{vo} - V_c \sin K_{co}}{V_{oto}}]$$

where $K_{vo,}V_v$, $K_{co,}$ and V_c, = the values of initial course and speed of the vessel and target accordingly; V_{oto} = initial relative speed:

$$V_{oto} = [V_v^2 + V_c^2 - 2 V_v V_c \cos(K_{vo} - K_{co})]^{1/2}$$

For calculation the value of relative angular speed ω_{otb}, it is necessary to know the values of rate of turn of the vessel ω_{vb} and the target ω_c.

Calculation of the value relative angular speed ω_{otb} for a situation, when the vessel and target change course simultaneously is produced by the following analytical expression:

$$\omega_{otb} = \frac{V_v \cos(K_{vt})\omega_{vb} - V_c \cos(K_{ct})\omega_c}{V_v \cos(K_{vt}) + V_c \cos(K_{ct})} -$$

$$\frac{[V_v \sin(K_{vt}) - V_c \sin(K_{ct})] V_v V_c \sin(\Delta K_y + \Delta\omega_b t)\Delta\omega_b}{[V_v \cos(K_{vt}) + V_c \cos(K_{ct})] V_{ot}^{\ 2}}$$

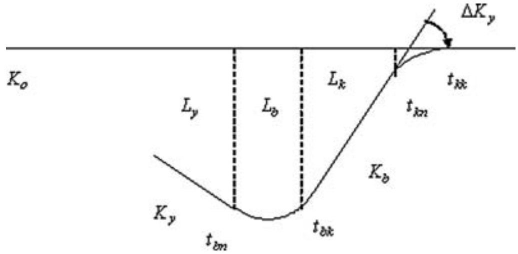

Figure 1. First type of returning trajectory in true motion.

where $K_{vt} = (K_{vy} + \omega_{yb}t)$; $K_{ct} = (K_{vy} + \omega_{yb}t)$; $\Delta\omega_b = \omega_{yb} - \omega_c$; $\Delta K = K_{vy} - K_{cy}$; K_{vy} = vessel's course deviation; K_{cy} = target's course deviation. K_{vy} and K_{cy} determined previously by using the method of flexible strategies for collision avoidance.

When target keep her course, $\omega_c = 0$ and, only the vessel change her course

$$\omega_{otb} = \frac{V_v \cos(K_{vt})\omega_{vb}}{V_v \cos(K_{vt}) + V_c \cos(K_{cy})} -$$

$$-\frac{[V_v \sin(K_{vt}) - V_c \sin(K_{cy})]V_v V_c \sin(\Delta K_y + \omega_{yb}t)\omega_{yb}}{[V_v \cos(K_{vt}) + V_c \cos(K_{cy})]V_{ot}^{\,2}}$$

The sign of the vessel's rate of turn depends on the side of turn Δ_y, so, that $sign(\omega_{yb}) = -sign(\Delta_y)$; $\Delta_y = 1$ when deviation to starboard.

2.3 *Identification of initial situation*

Belonging of the initial situation G to the subset M_{n1} is analytically expressed as follows:

$G \in Mn_1$, if $\{K_{oto} \in [\alpha_o + \pi/2, \alpha_o + \pi]$ and $\omega_{otb} > 0\}$,
or $\{K_{oto} \in [\alpha_o + \pi, \alpha_o - \pi/2]$ and $\omega_{otb} < 0\}$;
$sign(\omega_{Vb}) = -sign(\Delta_y)$

where α_0 = initial bearing from the vessel to the target.

Condition which describes belonging of initial situation G to the subset M_{n2}, expressed by a next correlation of relative initial course K_{oto} and sign of rate of turn ω_{otb}:

$G \in Mn_2$, if $\{K_{oto} \in [\alpha_o - \pi/2, \alpha_o]$ and $\omega_{otb} > 0\}$, or
$\{K_{oto} \in [\alpha_o, \alpha_o + \pi/2]$ and $\omega_{otb} < 0\}$;
$sign(\omega_{Vb}) = -sign(\Delta_y)$

Belonging of initial situation G to subset M_{n3}, is determined by analytical expressions:

$G \in Mn_3$, if $\{K_{oto} \in [\alpha_o - \pi/2, \alpha_o]$ and $\omega_{otb} < 0\}$, or
$\{K_{oto} \in [\alpha_o, \alpha_o + \pi/2]$ and $\omega_{otb} > 0\}$, or
$\{K_{oto} \in [\alpha_o + \pi/2, \alpha_o + \pi]$ and $\omega_{otb} < 0\}$, or
$\{K_{oto} \in [\alpha_o + \pi, \alpha_o - \pi/2]$ and $\omega_{otb} > 0\}$;
$sign(\omega_{Vb}) = -sign(\Delta_y)$

The type of returning trajectory depends on the subset to which the initial situation belongs.

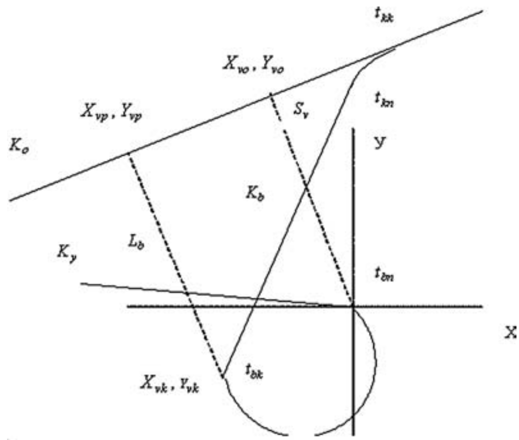

Figure 2. Second type of returning trajectory in true motion.

2.4 *First type of returning trajectory*

If G belonging to Mn1, the most preferable is the first type of vessel's returning trajectory to the planned route. This type of trajectory requires minimum time. The first type trajectory is shown on Figure 1.

This manoeuvre includes the turn of vessel from the course of deviation K_y to the returning course K_b, and, when approaching to the planned route the vessel shall turn from the course K_b on a programmatic course K_0, as shown on a Fig. 1 in true motion. The value of K_b depends on K_0 and ΔK_y. We proposed $\Delta K_y = 40°$.

The parameters of this manoeuvre are the values of: returning course K_b; the moments of beginning the turn t_{bn} and ending the first turn t_{bk}; the moments t_{kn} and t_{kk} – which determine the beginning end ending of the second turn. These parameters calculated by next equations:

$$L_k = R_c(1 - \cos\Delta K_y)$$

where R_c = radius of circulation of the vessel.

$$\Delta t_{bn} = 2\Delta K_y / \omega_V$$

$$t_{bk} = t_{bn} + \Delta t_{bn}$$

$$L_b = \frac{(L_y - L_k)}{\sin\Delta K_y}$$

$$t_{kn} = t_{bk} + \frac{(L_y - L_k)}{V_v \sin\Delta K_y}$$

$$t_{kk} = t_{kn} + \Delta K_y / \omega_V$$

2.5 *Second type of returning trajectory*

In case when G belonging to M_{n2}, the vessel use second type of returning trajectory which consist with the first turn to the same side as deviation from collision with angular speed $\omega_{yb} = -sign(\Delta_y)\omega_{ymax}$ and, then returning to the planned route by course K_b. The second type of trajectory is shown on Figure 2 in true motion.

On the first step it is necessary to determine the coordinates X_{vo}, Y_{vo} X_{vk} Y_{vk} X_{vp} Y_{vp}:

$$X_{vo} = -S_v \cos K_o$$

$$Y_{vo} = S_v \sin K_o$$

$$X_{vk} = R_c[\cos K_y - \cos(K_y - K_b)]$$

$$Y_{vk} = R_c[\sin(K_y - K_b) - \sin K_y]$$

$$X_{vp} = \frac{\cos K_o[X_{vo}\cos K_o + (Y_{vk} - Y_{vo})\sin K_o]}{(\cos^2 K_o - \sin^2 K_o)}$$

$$Y_{vp} = [Y_{vo} \sin K_o + (X_{vp} - X_{vo}) \cos K_o] / \sin K_o$$

Then we calculate the distance L_b:

$$L_b = \sqrt{(X_{vp} - X_{vk})^2 + (Y_{vp} - Y_{vk})^2}$$

The parameters of manoeuvre calculated by next equations:

$$t_{bk} = t_{bn} + [2\pi - (K_y - K_b)] / \omega_V$$

$$t_{kn} = t_{bk} + \frac{(L_b - L_k)}{V_v \sin \Delta K_y}$$

$$t_{kk} = t_{kn} + (K_b - K_o) / \omega_V$$

2.6 *Third type of returning trajectory*

If G belonging to M_{n3}, the vessel shall continue motion with relative course of deviation K_{oty} till the moment, when the returning to relative course K_{otb} guarantee that CPA will not less then L_d. This third type of returning trajectory shown on Figure 3 in relative motion.

In the beginning it is necessary to calculate the co-ordinates of points A,B,C:

$$X_A = L_d \sin \alpha_o$$

$$Y_A = L_d \cos \alpha_o$$

$$X_B = L_d \cos K_{otb}$$

$$Y_B = -L_d \sin K_{otb}$$

where K_{otb} = relative course of returning.

$$Y_C = \frac{G}{(\text{tg}K_{oty} - \text{tg}K_{otb})}$$

$$X_C = X_B + [\frac{G}{(\text{tg}K_{oty} - \text{tg}K_{otb})} - Y_B]\text{tg}K_{otb}$$

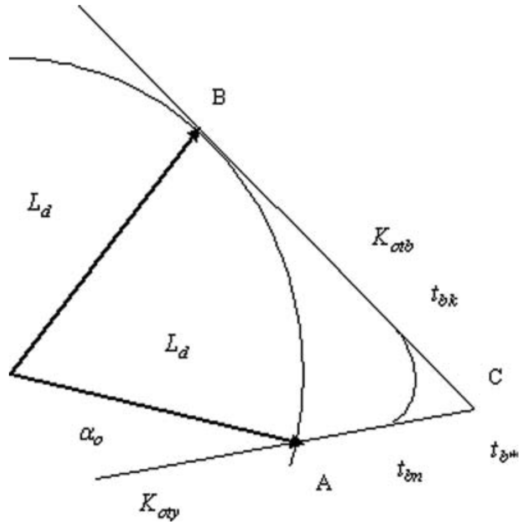

Figure 3. Third type of returning trajectory in relative motion.

where

$$G = X_B - X_A + Y_A \text{tg}K_{oty} - Y_B \text{tg}K_{otb}$$

K_{oty} = relative course of deviation.
Distance L_{AC} between points A and C calculated as follows:

$$L_{AC} = \sqrt{(X_C - X_A)^2 + (Y_C - Y_A)^2}\ .$$

The moment of time to turn t_{b*} is determined by the following formula:

$$t_{b*} = \frac{L_{AC}}{V_{oty}} = \frac{\sqrt{(X_C - X_A)^2 + (Y_C - Y_A)^2}}{V_{oty}}\ .$$

Amendment for ship's dynamic Δt_b is calculated on a formula:

$$\Delta t_b = \{\sin K_{otb} R_c (\sin K_b - \sin K_y) - \cos K_{otb} R_c (\cos K_y - \cos K_b) + V_c \tau \sin (K_{otb} - K_c)\} / [V_{oty} \sin (K_{oty} - K_{otb})]$$

$$\text{where } \tau = \frac{Abs(K_b - K_y)}{\omega_{vb}}.$$

The parameters of beginning and ending the turn to course K_b are calculated by next equations:

$$t_{bn} = t_{b*} - \Delta t_b$$

$$t_{bk} = t_{bn} + \tau$$

3 EXPERIMENTS AND RESULTS

For verification of correctness theoretical results the imitation software was designed for modeling the

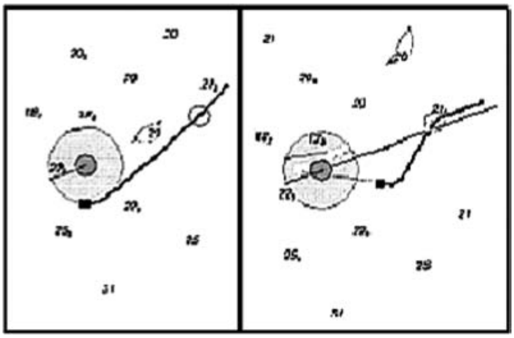

Figure 4. First type trajectory for safe returning.

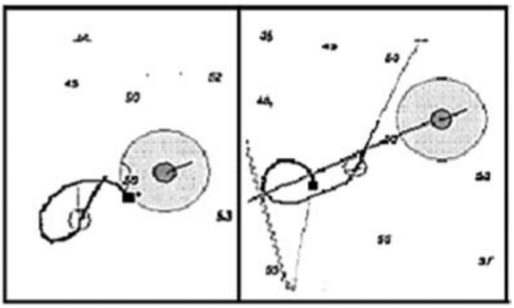

Figure 5. Second type trajectory for safe returning.

manoeuvre of returning the vessel to the programmatic trajectory of motion in different situations and with different types of returning trajectory. This computer program allows on the set initial situation choose the safe manoeuvre of returning and builds his trajectory on the screen. Information appears in relative and true motion.

On Figure 4 a situation is shown, when the safe manoeuvre of returning is possible by the trajectory of the first type.

Left part of screen shows the relative trajectory of the vessel in relation to the immobile target. Right part of the screen contains the trajectories of the vessel and target in true motion. As we can see, on relative motion, the distance between vessel and target is increasing. Black square shows the initial position of the vessel after deviation from collision.

On Figure 5 second type of safe returning trajectory shown.

Third type of safe returning trajectory shown on Figure 6.

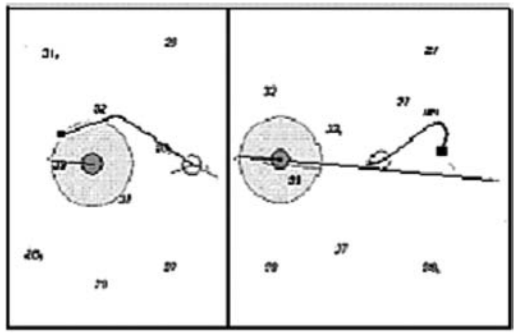

Figure 6. Third type of safe returning trajectory.

More than 100 different initial situations were generated and the parameters of manoeuvres of returning on the programmatic trajectory of motion are calculated and modelling. It appeared that 51% of manoeuvres had the first type of trajectory of returning, 37% is the second type and 12% is the third type. All manoeuvres chosen by the program were safe.

4 CONCLUSION

This paper presented the method which taking into account high level of vagueness of target's conduct, and increase safe returning of the vessel to planned route after deviation from collision.

Obviously, that at presence of co-ordination between a vessel and target on the stage of their returning to planned route provides more high safety returning.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

6.3
A study of marine incidents databases in the Baltic Sea Region

A. Mullai, E. Larsson & A. Norrman
Lund University, Lund, Sweden

ABSTRACT: A comprehensive risk analysis makes use of different datasets. Marine incidents data are essentially important datasets. The purpose of this study is to analyse marine incident databases in the BSR (Baltic Sea Region). The marine incident data in the region are inhabited by a wide rage of issues, such as limited data accessibility and availability, and the diversity in data quality, structure, amount, accuracy, degree of detail and languages. Preparing for the data analysis is a very cumbersome, labour intensive, time consuming and expensive process. Merging different datasets from different countries into a single dataset is a very difficult process, if not impossible for a complete data merging. The paper provides experiences on how to overcome some of these issues and proposes some suggestions for improvements in the future.

1 INTRODUCTION

1.1 *Background*

The Baltic Sea is the world's largest brackish body of water. It is designated as a PSSA (Particularly Sensitive Sea Area). More than 2000 large ships including large oil tankers are at any given time in the Baltic Sea (HELCOM 2005, Rytkönen et al. 2002). Maritime transport adversely affects different risk receptors in various forms and degrees of extents. Increasingly large amounts of different types of dangerous goods, including oil and oil products, gases and a wide range of chemicals, transported and handled in the BSR (Baltic Sea Region) (estimated between 300–1000 million tons per year) and accidents involving these goods are concerning issues for the countries in the region (TSE 2006). The most recent major oil spills that have occurred in the region are the cases of the m/v "Fu Shan Hai" (2003) (1200 tons of oil spilt) and the m/v "Baltic Carrier" (2001) (2700 tons of oil spilt). The costs of oil spills reported yearly and the worst-case scenarios in Öresund are respectively estimated $223,500 and between $150–300 million (Mullai & Paulsson 2002).

The DaGoRus project (Safe and Reliable Transport of Dangerous Goods in the Russian-EU Logistics Chain) is an European Union (EU)/Tacis project dealing with safe and reliable transport chains of dangerous goods. The project consists of a number of partners (including Lund University – LU, Sweden) and Working Packages (WP). It can be considered as continuation of the DaGoB project (Safe and Reliable Transport Chains of Dangerous Goods in the Baltic Sea Region) (INTERREG IIIB). The main objective of the project is to provide a risk analysis of dangerous goods transport in the BSR. The project is in many respects unique.

1.2 *Literature review*

An extensive literature review showed that a holistic view of the maritime risks in the BSR is limited, and they deserve a better understanding. Projects co-financed by the EU, including the BSR INTERREG Neighbourhood programme, have covered a wide range of issues concerning sustainable development in the region. Baltic Master (2005–2007) and OILECO (Integrating ecological values in the decision making process on oil) (2005–2007) are examples of the recent EU projects. None of these projects has particularly dealt with the risks of maritime transport of dangerous goods at a wider BSR context, including the Russian part. In addition, a few peer-reviewed papers have been confined to a limited number of risk issues, such as the m/v "Estonia" case (Soomer et al. 2001), marine pollution in coastal waters, oil spills detection and remote surveillance (Looström 1983) and monitoring by in-service aircraft (Von Viebahn & Gade 2000) and satellite (Kostianoy et al. 2005).

1.3 *Research questions and objective*

Marine incidents data are essentially important for the risk analysis. Time and financial resources are often limited for research projects, including the DaGoRus project. While the signing of the partnership agreement for the project was still pending, the relevant research questions for this particular study presented in this paper are: What is the current state-of-the-art marine incidents data in the region? Is it feasible to perform a comprehensive risks analysis for the entire region? The purpose of this study is to analyse marine incident databases in the BSR and propose suggestions for improvements in data accessibility, structure and quality.

1.4 *Materials, methods and paper outline*

After several months of communication with the responsible authorities of the BSR's countries, the following marine incident databases were acquired: 1) Danish Maritime Administration Database (DMA DB) (1997–2006; in Danish); 2) Finish Maritime Administration Database (FMA DB1 and DB2) – the database contains two datasets (1990–1996 and 1997–2007; in Finnish); 3) Swedish Maritime Administration Database (SMA DB) (1985–2007; in Swedish); and 4) Helsinki Commission Database (HELCOM DB) (1989–2006; in English). In section 3 of the paper, the main results and discussions including problems encountered during data collection are presented. The properties of the databases are described and compared. For the purpose of benchmarking with some of the best technology and practices in the field, in section 4, the USA's and world's largest incidents databases are described. Conclusions and suggestions for improvements are provided in section 5. Initially, in section 2, the concepts of risks and risk analysis are briefly described.

2 RISKS AND RISK ANALYSIS

2.1 *Maritime risks*

The risk is defined as the likelihood of consequences of undesirable events (Kaplan & Garrick 1981, HSE 1991). The terms "marine accident and incident" and "marine casualty" denote undesirable events in connection with ship operations (IMO 1996). The term "marine incident" is used to denote undesirable marine events, i.e. marine accidents, incidents and near missing events. The dangerous goods risks can be defined as the likelihood of consequences of hazardous release events (HSE 1991). Maritime transport risks are statistically verifiable technological and human activity risks. The maritime transport system and risks consists of many elements that are classified and defined by various coding systems.

2.2 *Risk analysis*

Contemporary risk management recognises the fact that the risk analysis, which is a rigorous scientific process facilitated by standardised frameworks and techniques, is prerequisite for the decision making process. The main purpose of every risk study is, to the best abilities of researchers and data and resources available, to provide decision makers with valid and reliable information and tools that would enable them to make informed decisions. The risk analysis varies from simple screening to major analysis that requires many years of efforts, substantial resources and a large team of experts using various risk analysis techniques and datasets. The main stages of the risk analysis are preparations for analysis, the analysis process and conclusions and recommendations. The first stage encompasses a wide range of activities, including identification, selection, compilation and preparation of the relevant datasets. Large amounts of diverse risk-related datasets are required, but the most important datasets are marine incident data.

3 MAIN RESULTS AND DISCUSSIONS

3.1 *Limited data accessibility and availability*

The Baltic Sea is an unique area in terms of sensitivity and diversity of countries surrounding the area. It is surrounded by nine different countries with different backgrounds, languages and practices, which may hamper data collection and merging and performance of a robust risk analysis.

Data accessibility may be an issue for the region. Our investigation suggests that marine incidents are recoded into databases in all BSR's countries. The websites of the relevant authorities in several countries of the BSR were reviewed. None of them had marine incident databases and other risk-related data available in electronic format for the public use. Requests for data acquisition were sent to all countries (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden), except Russia, and HELCOM. Signing of the partnership agreement with Russian partners was still (2007–2008) pending. Further, data collection for the Russian part was the responsible of another project group. Contact information was obtained from the SMA and other sources. Requests were sent to the maritime administrations, coast guards, bureaus of maritime casualty investigation and maritime safety inspectorates. The mail delivery system confirmed that request messages were successfully delivered, received and displayed on the recipient's computer. We were able to receive four (see Section 1.4) marine incident databases. Two databases were primarily obtained as the result of our personal contacts with the relevant authorities. Two other databases were obtained after considerable communication and assistance from our personal contacts. Some respondents did not reply or were not interested in cooperation. Requests were sent several times to those who did not reply. In some countries, the authorities may be unwilling or uncomfortable in providing data, in particular to external parties. Some interrelated reasons were cited inconvenient database format, limited human and financial resources, and data confidentiality.

Inconvenient database format for preparing and sending data in electronic format was cited by several respondents as one of the main issues. In one country, the incident data recorded up until December 2007 were available only at a relatively old computer. According to the respondent from that country, the data were compressed in a way that was practically impossible converting the data into a modern program format, including Excel format. It was very difficult and time consuming to convert all data manually. One respondent from another country replied that their organisation did not work with the Excel program as database. They were still waiting (2008) for the EMSA (European Maritime Safety Administration) database for the statistical analysis of ship incidents. Another one stated that their database contains personal and other information that are not necessary for the risk analysis. Further, converting their entire dataset into a convenient data format was time consuming and impossible task for them.

All respondents stated that preparing and sending data in electronic format were time consuming and labour intensive processes. Due to workload and other inquiries and in combination with limited human and financial resources, they were unable to provide data at all or in due time. They were too busy to assist us as their daily work was high on their priority list. One respondent wrote that he will not send the entire database. But, if we needed simple extractions they would be able to assist us. In case of a large extraction requiring special adjustments, they had to charge us for that.

Data confidentiality might have been one of the main reasons why some authorities did not reply. One respondent stated that in his country marine incident data are confidential. The data are only available for the accident investigation in his country and in his country language. A risk analysis for the BSR as a whole based on exhaustive data may not be possible should all the countries share a similar policy. Two respondents made reference to annual accident reports in pdf-format published on their organisations' website for the public use. The review of numerous accident reports showed that they were comprehensive and well prepared. However, a number of issues are observed. The data are mainly analysed and presented in form of descriptive or summary statistics, such as frequency tables and charts. Application of advanced inference statistics and specific risk analysis methodology were lacking. Reports are prepared by or for the responsible authorities. The knowledge comes from different corners, from practitioners and scientific community alike. However, because of systematic and rigorous processes employed, it is widely accepted that the knowledge generated by the scientific community has a higher degree of confidence, validity and reliability than the other forms. The scientific literature on the maritime risks for the region is, however, very limited. Studies concerning dangerous goods risks are largely confined to oil spills in the territorial waters of individual countries or in certain areas of the BSR. Further, integrating information from different reports is an impossible task.

3.2 *Diverse and incompatible data*

In this section, the data properties are explored (see Tables 1–6 and Figs 1–3). The HELCOM DB contains marine incidents reported by the BSR's countries. This dataset may serve, to some degree, as a sample for studying and drawing conclusions for the maritime risks in the entire region. However, the dataset is a relatively small and biased sample. The review of other databases showed that incidents are selectively reported to the HELCOM. Thus, during the period 1989–2006, a total number of 906 incidents (50 incidents per year) has been reported, of which 123 (13.6%) and 82 (9.1%) are respectively pollution incidents and incidents with no information about pollution. These numbers are smaller than pollution incidents and marine incidents recorded in the BSR's databases (e.g. SMA DB – 5778 incidents reported during 1985–2007). During the period 2004–2006, the Swedish Coast Guard alone has observed on average 308 spills per year. In addition, the HELCOM DB contains 42 variables, where 17 variables (40%) represent ship properties and consequences (Table 6 and Fig. 1). The consequences are confined to the occurrence of pollution (yes/no), the amount and type of pollutants.

Table 1. The main categories and examples of variables in the SMA DB (1985–2007).

Main category: examples of variables
Time: year, month, day, day of the week, time (hours)
Location: latitude and longitude, ports of departure and arrival, country, geographical areas, traffic area, fairway etc.
Ship: call sign, name, type, class society, nationality, built, size (dwt, brt, length), material etc.
Ship activity: ship activity (en-route, loading/discharging), activity onboard etc.
Exposure: crew, passengers, visitors, total numbers etc.
Cargo: description, type, amount, dangerous goods etc.
Event: type, event grading, description
Cause: categories codified, description
Other: pilot presence onboard
Environment: light, visibility, precipitation, sea, wind etc.
Consequence: human (fatality, injury, disappearance – crew, passengers, pilots, others, total), ship (damage – description, location, extent), environment (oil and other pollutants – type, amount)

Table 2. The categories, types and measurement levels of variables in the DMA DB (1997–2007).

Main category	Variable							
	Type*				Measurement level**			
	Str.	Nrc.	Date	Other	Nom.	Ord.	Sc.	Other
Time			4		4			
Location	1			2				3
Ship	6	2			6		2	
Event	2				1	1		
Cause	2				2			
Other	1				1			
Consequences	1			1	1			1
Total	13	2	4	3	15	1	2	4

* Variable type: Str. (String variables whose values are not numeric and therefore are not used in calculations), Nrc. (Numeric variables). ** Variable measurement level: Nom. (Nominal variables whose values represent categories with no intrinsic ranking), Ord. (Ordinal variables whose values represent categories with some intrinsic ranking), Sc. (Scale variables whose values represent ordered categories with a metric) (SPSS 16.0 for Windows 2007)

Table 3. The main categories, types and measurement levels of variables in the FMA DB1 (1990–1996).

Main category	Variable: Type*				Measurement level**			
	Str.	Nrc.	Date	Other	Nom.	Ord.	Sc.	Other
Time			5		5			
Location	4			2	4			2
Ship	11	2			11		2	
Ship activity	2				2			
Exposure		2					2	
Cargo	1	1			1		1	
Event	3				3			
Cause	4				4			
Other	1				1			
Environment	4				1	3		
Consequences	9	6		2	3	6	6	2
Response	1				1			
Total	40	11	5	4	36	9	11	4

*, ** See the foot note in Table 2

Table 4. The main categories, types and measurement levels of variables in the FMA DB2 (1997–2007).

Main category	Variable: Type*				Measurement level**			
	Str.	Nrc.	Date	Other	Nom.	Ord.	Sc.	Other
Time			5		5			
Location	3			2	3			2
Ship	10	3	2		12		3	
Ship activity	2				2			
Exposure		2					2	
Cargo	1				1			
Event	3				3			
Cause	4				4			
Other	1				1			
Environment	4	1			1	3	1	
Consequence	11	19		4	11		19	4
Total	39	25	7	6	43	3	25	6

*, ** See the foot note in Table 2

The variable labels are not properly designed and partly or completely missing in some variables. For example, the "ship type details" variable contains some 126 items.

The risk estimation and presentation require exhaustive data. The results obtained from the risk estimation may serve as an empirical ground for establishing risk criteria in the region. The risk criteria may serve as benchmarking standard for measuring and comparing the maritime risks in the individual countries and the region as a whole. In Sweden and other countries in the region, these criteria are lacking. Further, the reliability and validity of risk estimation and presentation depends very much on the data quality, diversity and amount. Therefore, it is important to perform a comprehensive risk analysis based on all datasets available. The best alternative is to merge

Table 5. The main categories, types and measurement levels of variables in the SMA DB (1996–2007).

Main category	Variable: Type*				Measurement level**			
	Str.	Nrc.	Date	Other	Nom.	Ord.	Sc.	Other
Time			3		3			
Location	10			2	10			2
Ship	13	3			13		3	
Ship activity	3				3			
Exposure		3					3	
Cargo	2				2			
Event	4				3	1		
Cause				1				1
Other	3				3			
Environment	5	1			3	2	1	
Consequence	8	26		1	5	3	26	1
Total	48	33	3	4	45	6	33	4

*, ** See the foot note in Table 2

Table 6. The main categories, types and measurement levels of variables in the HELCOM DB (1989–2006).

Main category	Variable: Type*				Measurement level**			
	Str.	Nrc.	Date	Other	Nom.	Ord.	Sc.	Other
Time			4		4			
Location	1			2	1			2
Ship	10	7			10		7	
Cargo	1				1			
Event	2			1	2			1
Cause	4				4			
Other	3				3			
Consequences	6	1			5	1	1	
Total	27	8	4	3	30	1	8	3

*, ** See the foot note in Table 2

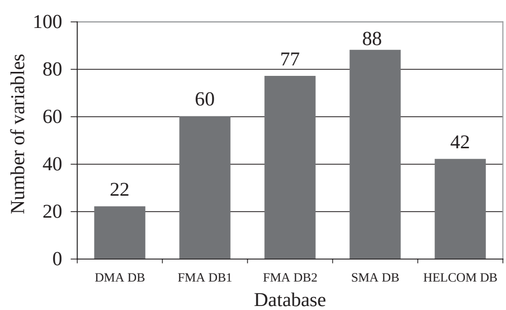

Figure 1. The number of variables in databases.

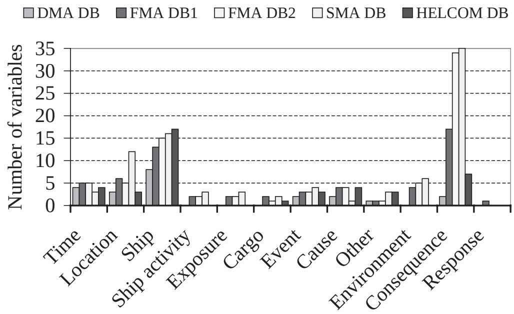

Figure 2. Comparison among the main categories of variables in databases.

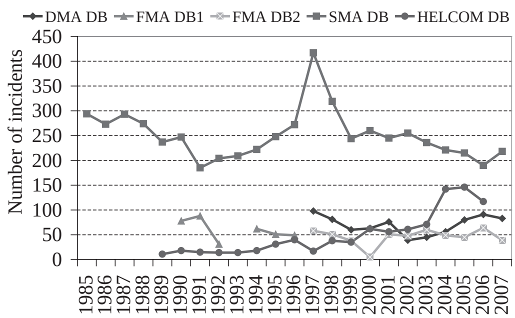

Figure 3. Comparison among periods and numbers of marine incidents recorded in the databases.

all datasets into a single dataset. A precondition in the data merging process is that all variables must be compatible, i.e. they have to share similar properties including variable type, number, label, and value and measurement level. Variables are not organized in any particular order in the databases. Based on the SMA DB, variables are labelled and organized in main categories (Table 1). A complete data merging, which is merging all databases including all cases and variables, is not possible. Merging parts of datasets may be possible, but considerable time, resources and expertise are required. This process includes translation, codification and de-codification and design and re-design of variables, conversion of data from Excel to SPSS data format, data merging and filtering. One case history is one A4 paper text (multiplied by ca 8000 incidents) and many variables are string or text format variables written in different languages. Text format variables contain very important information. The databases are mainly designed based on the DAMA coding system, which was originally agreed (1990) by Scandinavian countries for registration and analysis of marine incidents. The FMA DB and SMA DB share more in common than the two other databases. Deviations from the code and changes are also observed within the same database (e.g. FMA DB). The labels of many variables in the FMA DB are coded according to the DAMA coding system. These variables must be de-codified. The databases are specially designed databases, which may be inconvenient for converting data into advanced statistical program formats. The data were sent to LU in an Excel format. Data analyses and result presentations with this data format are limited. The present Excel data format of the databases is not readily convertible to the statistical program format. The data are organized on the "case" and "variable" bases. It is unclear whether the case histories are compiled on "event" or "ship" bases. In many cases, in a single incident two or more ships have been involved. The DMA DB is confined to a very limited number of events such as collision, grounding and fire. In one database, many cases were deleted. The SMA DB and FMA DB contain incidents that have occurred in the respective country territorial waters for all nationalities and ships flying the respective country flag outside the territorial waters. Therefore, variables should be designed for filtering or sampling purposes. In terms of data properties and structure, there are considerable discrepancies among the databases (Tables 2–6 and Figs 1–3). Only a very few variables are compatible. There are significant gaps in the number, category, type and measurement level of variables. The string (Str.) and nominal (Nom.) variables dominate (51–75%) all databases. The second largest numbers of variables are scale (Sc.) and ordinal (Ord.) variables (10–38%). More analysis methods are applicable to scale and ordinal variables than nominal variables. The variables for measuring risks of maritime transport of dangerous goods are very limited, if not lacking for certain databases.

4 INCIDENT DATABASES IN THE USA

The study of many incident databases (see Mullai 2004) show that, in terms of the public accessibility and amount, diversity, accuracy, quality of dangerous goods risk-related data, the USA is one of the most advanced countries in the world. Many types of data are free of charge and available for public use in the Internet. The USA Freedom of Information Act (1974) requires all federal and national organisations to make data available in electronic form to the public. Hazardous Material Information System (HMIS) and National Response Center (NRC) databases are two of the USA's and the world's largest databases in the field. They are available to both scientific and practitioner communities. The HMIS database (ca 200,000 case histories organised in more than 180 variables) records all dangerous goods incidents occurring in all modes of transport. The NRC database (over a half million case histories organised in more than 230 variables) records all incidents involving all types of hazmat discharges into the environment anywhere in the USA and its territories. The data are reported by individuals and a wide range of organisations and agencies, and cover a wide range of systems of the USA's chemical supply chain. In contrast to the BSR's databases, both the USA's databases offer many advantages, including massive, diverse, high quality and very well organised data, no restriction and easy data access via the Internet, and very convenient data format. Our experience (see Mullai & Larsson 2008) shows that data preparation and analysis are significantly less time consuming, resource and labour intensive than working with the BSR's databases. The incidents recorded to all BSR's databases combined are only a small fraction of the HMIS and NRC databases.

5 CONCLUSIONS AND RECOMMENDATIONS

With reference to the research questions, merging all databases into a single dataset and performing a detailed risk analysis for the BSR may not be possible due to issues explored in this study. However, a risk analysis based on partly merged datasets is feasible. Some of the issues are partly attributed to different practices, priorities and languages. The marine environment and safety issues are gaining more attention in the region. In order to tackle some of the issues, we suggest the following solutions: (i) Enhance cooperation among maritime authorities and other parties in the region. Projects like the DaGoRus project and conferences like the TransNav 09 can contribute to cooperation. They can serve as forums where problems and solutions are identified and discussed, stakeholders meet and information is disseminated. (ii) Improve and harmonise marine incident databases in the BSR. Immediate changes cannot be expected in the near future as several databases are designed based on the established coding system. Significant changes may render many years (two decades) of data records incompatible. Therefore, the process should be well studied and performed in a stepwise manner. (iii) Marine incident data should be made publicly available in electronic format via the Internet, at least for the research purposes. The USA experience can serve as an inspirational example. (iv) Upgrade data compilation systems. (v) Improving the HELCOM DB is a good solution, which include reporting all marine incidents (accidental and deliberate events) occurring in the BSR, improving the quality of variables and ensuring a higher degree of data completeness. The maritime risks, including risks due to the large and increasing amounts of dangerous goods, deserve a better understanding and management. These can be achieved only by united efforts.

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6.4
The display mode for choosing the manoeuvre for collision avoidance

L. Vagushchenko & A. Vagushchenko
Odessa National Maritime Academy, Odessa, Ukraine

ABSTRACT: The display mode is intended for facilitation of building strategies for collision avoidance by so-called B-manoeuvres. It can be used in ECDIS, ARPA and the simulator systems. B-manoeuvre includes the segment of deviation at a certain angle from the initial course and at the end of it the segment parallel to the initial way's line (planned route). The offered mode is based on the use of forbidden domains for B-manoeuvres. These domains allow choosing parameters and beginning moment of B-manoeuvre for collision avoidance with one or a few vessels. The account of presence of navigation hazards at the choice of B-manoeuvre is produced by setting the borders of maximum lateral shifting from planned route. The offered mode enables visual drafting of strategies for collision avoidance with vessels by successive B-manoeuvres. It is possible to use this mode as basis of computer search of strategies for collisions avoidance with a few targets.

1 INTRODUCTION

Forming of a model of environment is one of major tasks of the control systems. This model must adequately reflect an environment, to provide the high level of understanding of situations and serve as a substantial auxiliary mean at the search of decisions. Choosing one such model of environment for different situations of vessels interaction is difficult, because belonging of elements of environment and properties of operating ship to the categories ≪substantial≫, "unimportant" changes in them. It is also difficult to get the universal method of decision for preventing collisions. It is better to determine the environment model and methods of decisions as it applies to different situations. Then the choice of strategies of conduct will be simpler, and they – more precise. Therefore the local problem of development mode for presentation situation of vessels interaction and choosing an effective B-manoeuvre for collision avoidance and passing at a safe distance of targets was set.

2 FORBIDDEN DOMAIN FOR B-MANOEUVRE FORMING

It is accepted, that the alterations of course of operating ship are instantaneous. At such condition a B-manoeuvre looks like shown on a Figure 1, where K – planned course of operating ship; θ – angle of it alteration; Y – lateral distance from initial line of way to the operating ship at the end of deviation; S – length of deviation segment; C_H и C_K – points of course alteration. Course for deviation to starboard $(K+\theta)$ is designated K_S, to port $(K-\theta)$ – as K_P. An angle θ for collisions avoidance can undertake from 20° to 150°, and for returning to the initial line of way after passing vessels – from 10° to 45°.

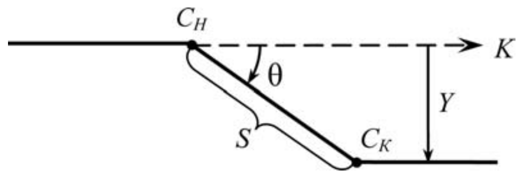

Figure 1. Parameters of B-manoeuvre.

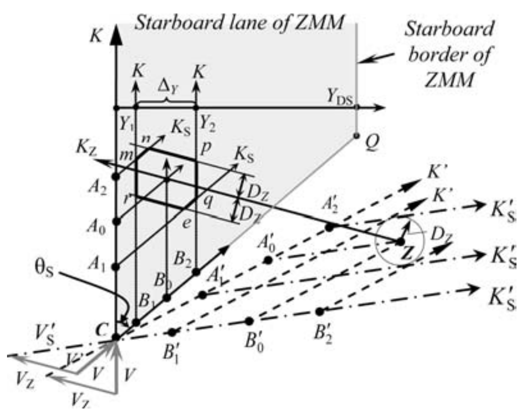

Figure 2. Principle of construction of forbidden domain.

Current positions of operating ship and scanned vessel (target) is shown below on Figure 2 by points C and Z. Taking into account presents of navigational hazards and necessity to determine only dander targets within navigable area the zone of manoeuvres and motion (ZMM) of operating ship is set (maximum allowable track margin for current leg). It is determined by width (Y_{DS}, Y_{DP}) of starboard and port lanes for shifting of operating ship at B-manoeuvres.

Beginning of lane of possible shifting to starboard forms a segment CQ on the course $K_S = K + \theta_S$ (Fig. 2), where θ_S = set alteration of initial course for B-manoeuvres to starboard. The butt end segment of port lane is directed parallel a course $K_P = K - \theta_P$ (θ_P = set alteration of initial course to port). The values of θ_S and θ_P can be both identical and different. The current position C of operating ship is considered as the appointed element of both lanes.

Principle of construction of forbidden domain (FD) is characterized in starboard lane on a Figure 2 (Vagushchenko, A.L. 2008), where

K, V = planned course and speed of operating ship;

K_Z, V_Z = course and speed of target;

K' и V', K'_S и V'_S = course and speed of operating ship in relation to a target at true courses K, K_S of operating ship;

D_Z = safe limit of distance between ships;

A_1, A_2 = points of turn from a course K to the course K_S for passing a target at distance D_Z;

B_1, B_2 = points of returning from a course K_S to the former course K for passing a target at distance D_Z;

mnpqer = forbidden domain;

O, A_0, B_0 = the FD center and points of turn from a course K to the course K_S and returning from a course K_S to the former course K for CPA = 0;

A'_0, A'_1, A'_2 and B'_0, B'_1, B'_2 = points on the lines of relative motion of operating ship, proper to the points A_0, A_1, A_2 and B_0, B_1, B_2;

Δ_Y – interval of lateral deviations from the planned way which provide close-quarters situation with a target at B-manoeuvres.

Distances S_{AJ} and S_{BJ} ($J = 0, 1, 2$) from a current place C of operating ship to the points A_0, A_1, A_2 and B_0, B_1, B_2 are determined on intervals of time t_{AJ} and t_{BJ} for arrival in these points. These intervals are calculated by values of S'_{AJ} and S'_{BJ} (CA'_0, CA'_1, CA'_2 and CB'_0, CB'_1, CB'_2) and V', V'_S:

$$t_{AJ} = S'_{AJ} / V'$$

$$t_{BJ} = S'_{BJ} / V'_S$$

$$S_{AJ} = V \cdot t_{AJ}$$

$$S_{BJ} = V \cdot t_{BJ} .$$

3 USE THE DISPLAY MODE FOR CHOOSING MANOEUVRES FOR COLLISION AVOIDANCE

The category of targets is determined on the location FD in relation to the ZMM borders (Fig. 3). If a target by transponder AIS reported the way points of the route or informed about the set manoeuvre, then an operating ship gets FD of this target taking into account accepted information (target 5, Fig. 3). The probability

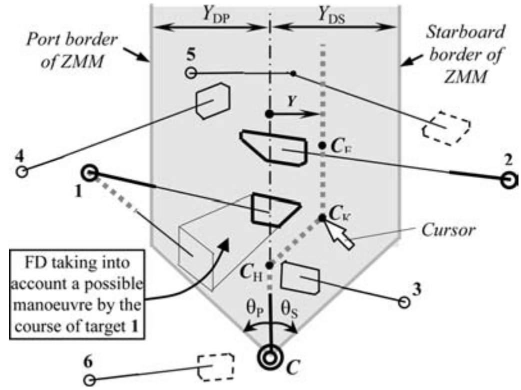

Figure 3. Situation presentation scheme.
TARGETS: 1, 2 – most dangerous and dangerous; 3, 4 – limiting; 5, 6 – indifferent.

of possible maneuvering of danger or obstacle vessels can be determined by the expert system (not presented in this paper). In this case the mode of situation can be added with the second FD for this target, proper to possible new course (target 1, Fig. 3). These two FD of target 1 allow forming the incorporated forbidden domain taking into account a possible manoeuvre of target.

The B-manoeuvre for collision avoidance is determined visually on the reflection situation on the screen. The B-manoeuvre is set by pointing the cursor, for example, on point C_K. The trajectory of future motion of operating ship would not cross the forbidden domains. Point C_E marked the end of B-manoeuvre, after which a dangerous ship can be considered finally passed. By a criterion for the choice of B-manoeuvre it is possible to take minimum distance of shifting (Y) from the planned line on condition that the degree of risk of collision with all targets will not exceed the legitimate value at the point C_E and manoeuvre will not conflict with ColRegs.

The next action is then planned. Depending on the circumstances one of three actions of operating vessel gets out after the first B-manoeuvre: motion along a new line parallel to the planned line (Fig. 4,a); returning on the planned line by B-manoeuvre (Fig. 4,b); proceeding by the course to next way point (Fig. 4,c). The borders of ZMM can be corrected accordingly, if necessary.

After this the point C_{E1} is undertaken as appointted element for new ZMM. In this ZMM forbidden domains are determined on the prognosis of motion of operating ship and targets. Similar to finding the first manoeuvre, the second and the following ones are planned, if necessary. The point C_{EJ} determines ZMM until operating ship will not come to this point, whereupon the current position of operating ship becomes the appointed element of this zone.

While searching B-manoeuvres at the beginning by default the values θ_S and θ_P are undertaken as the best from point of providing as noticeable a manoeuvre and prevention of losses of underway time ($\theta \approx 35°$). When

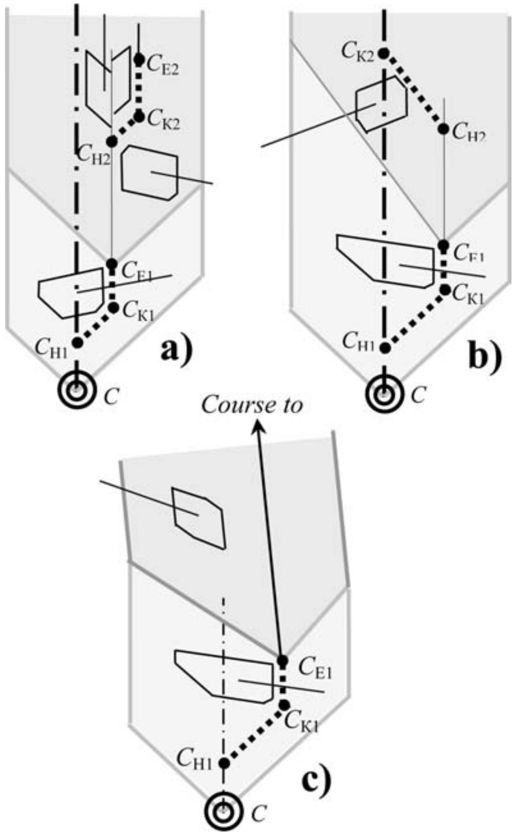

Figure 4. Variants of conduct after the first B-manoeuvre.

returning to the former line after deviation (Fig. 4,b), the value θ can be taken less.

If it appears that at the chosen values of parameters θ_S, θ_P, D_Z a safe manoeuvre does not exist, it is searched with other values – values of parameters θ_S, θ_P at the search are increased, and a value of parameter D_Z is decrease till the least allows value.

4 CONCLUSION

The offered mode for situations presentation simplifies the choice of manoeuvres by a course change for collision avoidance with a few vessels in open sea and in the confined waters. Advantages of this mode are:

- immobility of the domains in relation to ground, that allows to define manoeuvres for collision avoidance with mobile objects as with immobile;
- simplicity of account of navigation hazards by setting the borders of lateral shifting from planned way;
- possibility to form a strategy for collisions avoidance with a few targets by successive B-manoeuvres;
- possibility to use this mode as basis of computer search of strategies for collision avoidance in any situations.

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6.5
Defining of minimally admitted head-on distance before the ships start maneuvering

V.M. Bukaty & E.N. Dimitrieva
Baltic Fishing Fleet State Academy, Kaliningrad, Russia

ABSTRACT: Without stating the very fact of head-on situation, an attempt has been made to define the minimum admitted head-on distance between the ships in order to carry out safe maneuvering at a determined the closest point of approach, taking into account the ships' maneuvering characteristics.

1 INTRODUCTION

The practical use of Rule 14 article of COLREG-72 is complicated by non-indication of minimal admitted distance till the oncoming vessel for the purpose of the maneuver to keep well clear. The COLREG-72 Comments together with ship's guide textbooks recommend to start the maneuver «to act accordingly to the existing situation» for this case. But obscure maneuver start definition accompanied with the nearest admitted head-on distance (i.e. ships beam distance) at the keeping clear moment together with other factors may be the common cause of dangerous getting closer of ships which involve risk of collision or ending with collision. Unrestricted meeting distance between vessels before the maneuver and uncontrolled beam distance at the clear moment cause the vessels to take the clearing maneuver non-simultaneously. More of this, if one of the vessels watches the other have turned starboard, the former often sustains the present course and speed until the situation becomes threatening. But we should mind that the vessels' head off angles defining depend upon the head-on distance. These angles should be as such that at the moment of divergence the abeam distance between the vessels has no less than prescribed safe value. To fulfil such requirement navigators have to solve the task on vessels meeting at a fixed distance, that is to define their own vessels' maneuvers so as the distance between the vessels at the beam passage moment is no less than the prescribed value. So far this task is solved by navigators without any calculation but based upon their own experience and ocular estimation together with shaky ground of Rule 14 article of COLREG-72 as quoted «acting accordingly the factors of existing situation…».

2 ANALYTIC REVIEW

Taking into account the fact that a considerable number of collisions take place at the meeting vessels courses in particular (Karapuzov, A. I. & Mironov, A. I. 2005. Maneuvering…) there was suggested to bring under regulation navigators' actions at maneuvering for safe divergence. So we made some attempts in our articles (Zelenkov, A. I. 1999. The Distance…; Karapuzov, A. I. 1986. Determination…) define the minimal admitted distance between vessels approaching each other meeting on the almost reciprocal course by the minimal nearest admitted vessels' head-on distance criterion depending on rudder angle at the maneuver start. As the result we have deduced expression for defining minimal admitted distance S_{min} between the vessels at the maneuver start and for defining necessary head-off (turn) angles ΔC_A and ΔC_B for vessels A and B respectively to provide the divergence at the closest point of approach d_{cpa} (Fig. 1):

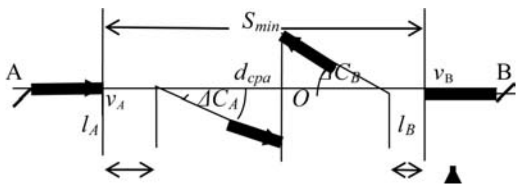

Figure 1. For calculation of minimal admitted distance between vessels approaching on reciprocal courses.

$$\Delta C_A = arctg \frac{d_{cpa}}{4S \min}\left(1+\frac{v_B}{v_A}\right)$$

$$\Delta C_B = arctg \frac{d_{cpa}}{4S_{\min}}\left(1+\frac{v_A}{v_B}\right)$$

$$S_{\min} = l_{1A} + l_{1B} + \frac{L_A + L_B}{2} + S_A + S_B$$

where v_A and v_B – the vessel's speed at the turn moment; l_{1A} and l_{1B} – the vessels' advance at moments

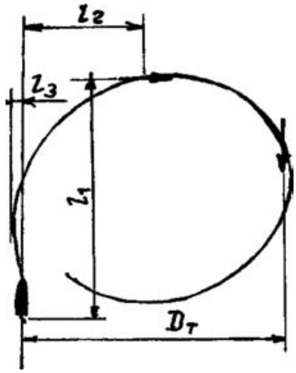

Figure 2. Center of vessel's gravity path on circulation.

of head-offs; S_A and S_B – the ways passed by the vessels within the wheel orders fulfilment; L_A and L_B – the vessels' lengths overall.

The above given task solution is eventually defective as in this regard the vessels were suggested to turn from their courses immediately while proceeding at rectilinear motion. As the result the distance, between the vessels' fore ends at moment of the O meeting point entry along with unaltered courses, taken as d_{cpa}, is not the nearest head-on distance as the actual distance exceeds it. Such a deficiency has been caused by consideration the vessels' motion straight but through maneuverable path, i.e. turning circle.

3 TASK SOLUTION

But starting from the rudder displacement (starboard as required by the COLREG Rule 14 in this case) the vessel is known to pass first so called «dead interval» (that is considerable for heavy-tonnage vessels) keeping the present course for a while. Than after declining the course to port that is called as the reversed bias l_3, the vessel will proceed to the turning circle (Fig. 2). In the theory of turning circle the advance l_1 is called a distance for which the center of gravity is shifted from putting the wheel to the vessel's exit to the point at the curve of the turning circle, that corresponds to the course alter through 90°. Meanwhile the forward bias l_2 (Snopkov, W. I. 2004. Ships'…; Woytkunsky, Y. I. & Perschitz, R. Y. & Titov, I. A. 1973. The Ships…) is the least distance from the previous course line to point on the turning circle curve, corresponding to the course alteration by the same value. The distance from the moment of the vessel's exit to the circulation start till her turn to 180° is called the tactical diameter D_T. The advance l_1 value, forward bias l_2 and the tactical diameter D_T are give in the vessel's maneuvering fact sheet inevitably.

The following correlations are typical for vessels of all types (Woytkunsky, Y. I. & Perschitz, R.Y. & Titov, I.A. 1973. The Ships…)

$$l_1 \approx D_T; \quad l_2 \approx 0{,}5 D_T; \quad l_3 \approx 0{,}1 D_T \tag{1}$$

Table 1. Circulation items of the «Atlantic» full-freezing trawler (FFT) type.

Rate of sailing	FSA 13 *kts*			HAS 10.5 *kts*		LSA 7 *kts*	
Rudder angle	15°	25°	35°	15°	35°	15°	35°
Circulation tactical radius, cab	2.35	1.73	1.51	2.16	1.40	1.99	1.25
Advance, cab	2.03	1.51	1.40	1.92	1.29	1.75	1.25
Forward bias, cab	1.27	0.97	0.93	1.08	0.80	1.02	0.71

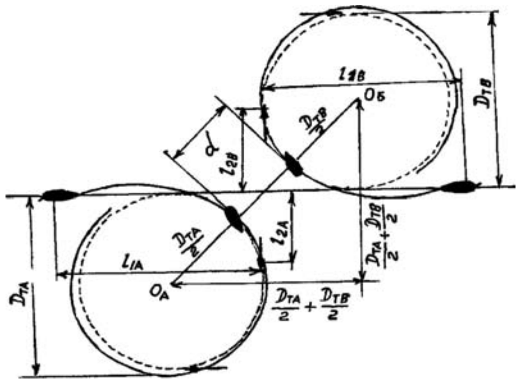

Figure 3. Scheme of vessels' manoeuvering at divergence as per COLREG-72 Rule 14 at the minimal distance equal to advances sum.

The tactical circulation radius depends on the rudder angle ψ and vessel's rate of sailing ν. Based on field testing results Table 1 presents the following data: tactical circulation radius, the advance, the forward bias of «the Atlantic» type full-freezing trawler (FFT) at full steam ahead (FSA), at half steam ahead (HSA), at slow steam ahead (SSA), for rudder deflection by 15°, 25°, 35° (Karapuzov, A. I. 1984. Ships…).

As we can see from the table in fact the forward bias l_2 makes 50% of the tactical diameter D_T on an average, and the advance is approximately equal to the tactical diameter D_T.

Suggested that the both vessels navigators having known the tactical diameters of his vessel as well as the oncoming vessel's one (e.g. these data could have been included within the information transmitted by AIS) began the passing maneuver in accordance with COLREG Rule 14 with turning starboard for the distance S_{min} equal to sum of advances $l_{1A} + l_{1B}$ of own (A) and oncoming (B) vessels (Fig. 3).

We can take adequately that vessels' turning effect centers, before they achieve the course altering by 90°, move along curves coinciding with circles which diameters are equal to tactical diameters D_{TA} and D_{TB} of vessels (indicated with dashed lines at Fig. 3).Then as we can see from figure 3 D_{TB} the closest range d to which the vessels' centers of gravity will get closer, will be placed at straightway crossing centers of circles with diameters D_{TA} and Consequently, taking into account the geometrical configuration of the task coming from figure 3 we can write down as follows:

$$\left(\frac{D_{TA}}{2}+d+\frac{D_{TB}}{2}\right)^2=2\left(\frac{D_{TA}}{2}+\frac{D_{TB}}{2}\right)^2 \quad (2)$$

Then we calculate the following from equation (2):

$$d=\left(\frac{D_{TA}}{2}+\frac{D_{TB}}{2}\right)\left(\sqrt{2}-1\right)=0{,}41\left(\frac{D_{TA}}{2}+\frac{D_{TB}}{2}\right) \quad (3)$$

However we have not considered the reduction of the closest vessels' head-on range due to that while turning circle there will be inevitably leeway angle β which can be estimated on the approximate correlation (Karapuzov, A. I. & Mironov, A. I. 2005. Maneuvering…) by reason of its low values (order of 10°–15°):

$$\beta=0{,}9\frac{L}{D_T} \quad (4)$$

where L – the vessel's length.

While the vessel is sailing with leeway angle she will occupy a lane which width S is found from the expression:

$$S=L\sin\beta+B\cos\beta \quad (5)$$

where $B =$ the vessel's breadth.

Thus we can draw the following for defining the closest point of approach d_{cpa} between the two vessels:

$$d_{cpa}=d-\frac{1}{2}\left(S_A+S_B\right) \quad (6)$$

where S_A and S_B – the A and B vessels motion lane widths respectively.

Otherwise we can obtain from (3)–(5) as follows:

$$d_{cpa}=0{,}41\left(\frac{D_{TA}}{2}+\frac{D_{TB}}{2}\right)- -\frac{1}{2}\left(L_A\sin(0{,}9\frac{L_A}{D_{TA}}+L_B\sin(0{,}9\frac{L_B}{D_{TB}}\right) \quad (7)$$

where L_A and L_B – the vessels A and B lengths respectively.

The diameter tactical $D_{T\psi}$ at the arbitrary rudder angle ψ is connected with diameter tactical during rudder deflection full helm ($\psi = 35°$) D_{T35} by correlation (Karapuzov, A. I. & Mironov, A. I. 2005. Maneuvering …)

$$D_{T\psi}=6.1\psi^{-0{,}509}D_{T35} \quad (8)$$

Using this connection between diameter tactical and rudder angle we can attempt to define the rudder angle necessary for divergence at the prescribed nearest distance. However if rudder angles are small so the vessel's circulation diameter is larger and consequently the nearest distance between vessels is larger at the distance accepted by us for divergence that is equal to vessels' advances sum. In this case we can agree to limit the rudder angles to 15° on both vessels.

For instance, we calculate the closest point of approach between vessels of FFT the «Atlantic» type that proceed at full steam in reciprocal to each other's courses. According to the table 1 data the at the rudder angle of 15° $D_T = 436$ m (2.35 cab.). The vessel's length is 82.2 m, breadth is 13,6 m. According to (7) we obtain $d_{cpa} = 337.5\ \text{m} \approx 1.8$ cab. Thus if two FFT the «Atlantic» type vessels start divergence maneuvering simultaneously at the following distance between them

$$S_{min}=l_{1A}+l_{1B} \quad (9)$$

according to COLREG Rule 14, having displaced rudder starboard 15°, they will get closer at the divergence distance no more than 1,8 cab. that corresponds to mutual vessels' position abeam. After this maneuver the vessels can set their previous courses since theoretically the head-on distance is sufficient for safe divergence, the more so the vessels will make the same course for some time passing the dead interval. At least the closest point of approach will not exceed the hydrodynamic coupling distance that amounts to no more than half of lesser vessel's hull width at parallel reciprocal courses (Snopkov, W.I. 2004. Ships'…).

We draw the attention that if the distance exceeds S_{min} (9) at the divergence maneuver start, the nearest vessels' approach distance will not increase really provided turning to previous courses are carried out at the moment of mutual abeam vessels' position. It is determined by the fact that while displace the rudder to the previous courses accounting the dead interval and reversed bias the abeam distance between vessels will be sustained approximately the same as it was at the mutual abeam position of vessels at the circulation curve. To increase the vessels' closest of point approach in any case it is necessary to make turns to the previous courses after the vessels' mutual abeam position, for example, when courses are altered to 90°. In this case upon the vessels' returning to their previous courses they will diverge at the abeam distance approximately equal to fore biases sum. For the case with FFT the «Atlantic» type vessels this would mean that they diverge at the abeam distance amounting according to the table 1 $d_{cpa} \approx 2.5$ cab.

4 CONCLUSION

Our suggested divergence maneuver regimentation at approaching of vessels on reciprocal courses we find advantageous as it complies with the common sense: the more heavy-tonnage the vessels are the more is the closest point of approach between them during the divergence. For example, at full steam while rudder displacement the vessels 200 m long and 20 m wide will have the circulation diameters of order 0.5 mile (Karapuzov, A. I. & Mironov, A. I. 2005. Maneuvering…) While rudder displacement to 15° the circulation diameters will make up 1 mile according to (8). Therefore in our opinion the vessel's closest point of approach should make up about 1 mile which is crucially sufficient for safe vessels' divergence maneuver according to our suggested maneuver regimentation of vessels' minimal distance that is equal to doubled sum of vessels advances, on condition that the rudder displacement is 15°, turning to previously set courses after the vessels turn is to 90° on circulation path.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

6.6 Collision scenario-based cognitive performance assessment for marine officers

H. Kim & H.-J. Kim
Marine Transportation & Pollution Response Research Department, MOERI/KORDI, Daejeon, Korea

S. Hong
Chungju National University, Chungju, Korea

ABSTRACT: The overall aim of this paper is to determine a fatigue factor that can be applied to human performance data as a part of a software program that calculates total cognitive performance. This program enables us to establish the levels of cognitive performance in a group of marine pilots in order to test a decision-making task based on radar information. This paper addresses one of the factors that may contribute to the determination of various fatigue factors: the effects of different work patterns on the cognitive performance of a marine pilot.

1 INTRODUCTION

A decrease in crew performance for maritime works can be caused by the complex causation related to physiological, psychological, and external sailing factors (Kim et al., 2004). A procedure in maritime accidents caused by the reduction of crew performance can be explained as follows. Physiological, psychological, and external sailing factors affect the working process of a marine pilot directly or indirectly. These factors decrease physical and psychological abilities and that ultimately affect decreases in the cognitive performance of crews as ultimate factors. The decrease in cognitive performance causes mistakes, such as negligence of lookout, and that lead to a direct cause of accidents.

As shown in Figure 1, human cognitive performance represents all abilities of the elements presented in an information processing model of human (Wickens, 1992). However, it may not be necessary to measure the all abilities of such cognitive elements in a project that investigates the cognitive performance of a worker who processes given works. In general, there exist cognitive elements to play a definitive role in the effective performance for given cognitive works. Because these elements are enough to perform such given works except for a decrease in cognitive performance caused by certain diseases, it is possible to estimate the cognitive performance of a worker in given works using such definitive elements in the cognitive works.

Subjective methods, physiological monitoring, and task loading methods are generally used to evaluate these cognitive performances. Also, these methods have been applied to some high risk industries, such as national defense, road transportation, railways, aerospace, process control, and power generation in which the selection of a method usually depends on specific requirements related to each industry.

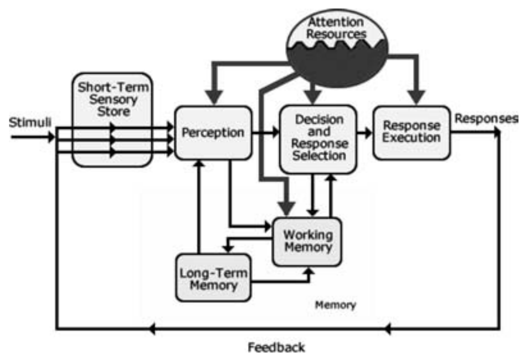


Figure 1. Model of human information processing.

A representative study in subjective methods is the Modified Cooper-Harper Scale (MCH) (Wierwille and Casalli, 1983) that complemented the Cooper-Harper Scale, which was developed to evaluate the performance of the handling characteristics of military aircrafts in the end of the 1960s. In addition, the NASA TLX (Hart and Staveland, 1988) is a biploar-rating scale-based study using self-report scores.

In the case of the physiological monitoring, there are some studies on the variation of human physiology responses, such as Electroencephalogram (EEG), Electrocardiogram (ECG), Electrodermal activity (EDA), and Electrooculogram (EOG), according to task demands (Andreassi, 2000).

The task loading methods represent an engineering approach that is to measure workloads based on the estimation of task demands. The Task Analysis Workload (TAWL) Methodology (Mitchell, 2000) that was developed by using the US Army Light Helicopter Experimental Program and the Operator Function Model-Cognitive Task Analysis (OFM-COG) (Lee and Sanquist, 2000) that was developed to evaluate workloads in ship-borne automation systems applied these methods.

Marine officers perform various cognitive works, such as signal detection, situation recognition, general judgment, and other related works, in their ship operation jobs. For instance, it can be considered as perceptual ability to recognize target ships approached to their own ship through radars and the naked eye, memory ability in a steersman who memories the commands from his captain, and judgment ability to determine the scale of the conversion (heading) of the bow to avoid the collision with approached target ships. It is difficult to guarantee that such cognitive works occur intermittently or sequentially. Requirements in excessive cognitive performance may cause some mistakes in marine officers and that lead to maritime accidents (Lee, 2005). However, there are still limited studies on the quantitative evaluation of the cognitive performance for maritime officers.

Thus this study developed a maritime collision scenario-based cognitive performance evaluation system for marine officers. The evaluation criteria was configured by applying practical experiments for a group of marine pilots and verified the system through practical applications for cadet marine pilots. Because this system is able to evaluate general cognitive performance of marine officers, it is able to play a role in the avoidance of accidents based on their own awareness on such accidents by transferring the results of the evaluation of physical and psychological conditions through applying a test for a short period of time before going on duty or boarding.

2 COLLISION SCENARIO-BASED COGNITIVE PERFORMANCE ASSESSMENT

In this study, we developed a computer program to evaluate the abilities of signal detection and decision-making task in cognitive performance for marine officers. The objective of this program is to measure the perceptual ability (signal detection) of marine officers for searching other ships through the information presented on radars and the judgment ability (situation recognition or decision-making) that determines the direction and speed of a ship to avoid the collision with other ships. The cognitive performance evaluation program for marine officers developed in this study reflects general cognitive abilities for operating a ship and measures the performance through a 10 minute simple test before going on duty or boarding.

Also, this system is a program that measures the cognitive performance of a marine pilot who controls the heading and speed of a ship using the information presented in a ship operation process. In general, the information given to marine officers is the data presented on radars and speed information of their own ship. The marine officers possibly observe a planned course and control the heading and speed of their own ship in order to avoid the collision with other ships. After avoiding possible collision, the marine officers should return its own course.

Figure 2. Screen of an evaluation of cognitive performance.

Table 1. Types of scenarios.

No.	Scenarios	Direction of Screen
1	Rule 14: Head-on Situation	Normal
2	Rule 15: Crossing Situation	Normal
3	Rule 14: Head-on Situation	Normal
4	Rule 13: Overtaking	Normal
5	Rule 15: Crossing Situation	Normal
6	Rule 13: Overtaking	Normal
7	Rule 10: Traffic Separate Schemes	Normal
8	Rule 15: Crossing Situation	Opposite
9	Rule 14: Head-on Situation	Opposite
10	Rule 13: Overtaking	Opposite

Figure 2 illustrates a screen image of the cognitive performance evaluation. The left side of the screen represents the information of target ships (DCPA, TCPA, Heading, Speed, Bearing, and Range) and the right side shows the input menu of the information for changing a course. Whereas, the DCPA (Distance at Closest Point of Approach) shows the estimated distance to the recent closest point and the TCPA (Time to Closest Point of Approach) demonstrates the estimated time to the recent closest point. In order to attempt a proper action for collision avoidance, it is necessary to input the action time for collision avoidance, heading and speed at the starting point, termination time for collision avoidance, and heading and speed at the termination point.

This system configured 10 collision scenarios as noted in Table 1 by varying the number of target ships, heading and speed, and bearing based on the four rules presented in the International Regulations for Preventing Collisions at Sea (1972).

Table 2. Evaluation criteria for "Rule 15".

Scores Measures	10 points	5 points	0 point
1 Decision	Starboard	Reduce Speed	Port or Stand-on
2 Time to Change of course (CT)	0–5 minutes	5–10 minutes	Over 10 minutes
3 New Heading (CH)	040–050	020–040 050–060	0–020 >060
4 New Speed (CS)	Same (18)	0–18	>18
5 Time to Return to course (RT)	10–15 minutes	5–10 minutes	<5 minutes >15 minutes
6 Final Heading (RH)	359–001	350–359	>001 <350
7 Final Speed (RS)	18	10–18	0–10 >18
8 DCPA	1.0–2.0	2.0–3.0 0.7–1.0	<0.7 >3.0
9 Total Response time	<1 mins	1–3 minutes	>3 minutes
10 Distance of new track as a ratio of original track	<1.05	<1.25	>1.25

Although the Scenarios 1 and 3 show the same situation, "Head-on Situation", target ships represent different headings and speeds. The Scenarios 2 and 5 show the same situation, "Crossing Situation", but they represent different numbers of target ships, such as one and two ships. Also, the Scenarios 4 and 6 show the same situation, "Overtaking", but they demonstrate different headings and speeds.

This system configured a scoring index to evaluate the cognitive performance of marine officers as follows.

1. Collision avoidance ability
2. Decision-making time
3. Degree of deviation

The evaluation criteria were produced for each scenario with advice from professional marine pilots. They were not participated in the experiments. Table 2 shows the evaluation criteria for "Crossing Situation".

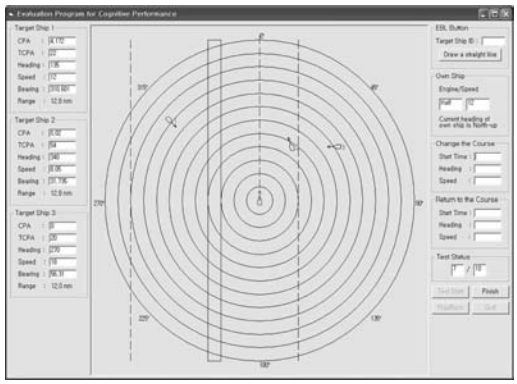
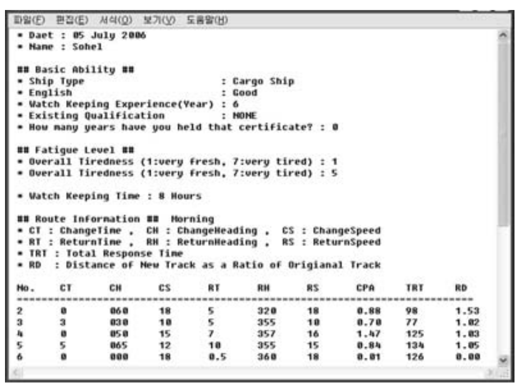


Figure 3. Screen of the scenario of "Rule 10 (TSC)".



파일(F) 편집(E) 서식(O) 보기(V) 도움말(H)

- Daet : 05 July 2006
- Name : Sohel

Basic Ability
- Ship Type : Cargo Ship
- English : Good
- Watch Keeping Experience(Year) : 6
- Existing Qualification : NONE
- How many years have you held that certificate? : 0

Fatigue Level
- Overall Tiredness (1:very fresh, 7:very tired) : 1
- Overall Tiredness (1:very fresh, 7:very tired) : 5

- Watch Keeping Time : 8 Hours

Route Information ## Morning
- CT : ChangeTime , CH : ChangeHeading , CS : ChangeSpeed
- RT : ReturnTime , RH : ReturnHeading , RS : ReturnSpeed
- TRT : Total Response Time
- RD : Distance of New Track as a Ratio of Origianal Track

No.	CT	CH	CS	RT	RH	RS	CPA	TRT	RD
2	0	060	18	5	320	18	0.88	98	1.53
3	3	030	10	5	355	10	0.70	77	1.02
4	0	050	15	7	357	16	1.47	125	1.03
5	5	065	12	10	355	15	0.84	134	1.05
6	0	000	18	0.5	360	18	0.01	126	0.00

Figure 4. Screen of the test results.

3 EXPERIMENTS & RESULTS

Three professional marine pilots and five cadet marine pilots were participated to verify the evaluation of the cognitive performance assessment system for marine officers developed in this study. Except for Scenario 1, which was applied as a pretest, experiments were applied to other nine Scenarios.

Figure 3 shows a screen image of the collision scenario of "Traffic Separate Schemes". An experiment based on this scenario represents the input and analysis data as shown in Figure 4.

In the results of these experiments, the professional pilots showed higher scores than cadet marine pilots, average 90.2 and 74.0.

Also, as shown in Figure 5, the total scores of the professional pilots for scenarios showed high levels more than 10 points compared to that of the cadet pilots.

For a comparison and analysis of this data, a 5% level of significance paired-wised t-test was conducted. According to the analysis result, there was a statistically significant difference in the total scores

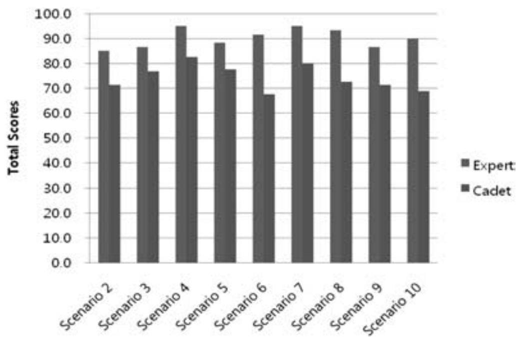


Figure 5. Comparison of the total scores by scenarios.

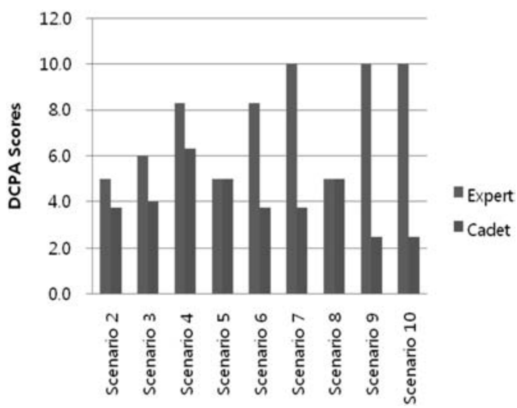


Figure 6. Comparison of the DCPA scores by scenarios.

between the professional pilots and the cadet pilots for each experiment subject ($p = 0.015$).

In addition, in the results of the comparisons of the Distance to the Closest Point of Approach (DCPA) that is the most important factor to achieve collision avoidance, the professional pilots showed higher scores than cadet pilots for all scenarios as illustrated in Figure 6 in the "Scoring Index".

For a comparison and analysis of this data, a 5% level of significance paired-wised t-test was conducted. According to the analysis result, there was a statistically significant difference in the DCPA scores between the professional pilots and the cadet pilots for each experiment subject ($p = 0.028$).

Regarding future studies, it will attempt to guarantee the evaluation data through additional experiments in order to complement the cognitive performance evaluation system for marine officers and that will increase the reliability of this system.

4 CONCLUSIONS

In recent years, various sailing equipments, such as GPS, ARPA, ECDIS, AIS, VDR, and hull monitoring system, have been introduced to ship operation and the development of such hardware still have been conducted.

However, the improvement and effort on the ship operator-based related software are still limited and in an elementary step.

The present circumstance is due to the lack of investment in this filed even though there are some words on the marine accidents that usually caused by human factors. It can be considered that there are still lack of studies on physical, psychological, and cognitive performance for marine officers who guarantee the safety of sailing using advanced equipments and consideration.

This study attempted to develop a cognitive performance assessment system for marine officers that evaluates the cognitive performance of marine officers through a simple way before going on duty or boarding and provides the results of the evaluation to the pilot as a warning message for avoiding marine accidents caused by the decrease in cognitive performance of marine officers.

In addition, there exist some problems for the reflection of the importance in detailed items that consist of the reflection issues of difficulties and evaluation criteria according to collision scenarios in the experiment and analysis processes in this study.

The result of the analysis in this study includes some problems of the limited subjects and quantitative evaluation criteria. Also, the cognitive performance assessment system developed in this study included the evaluation of the cognitive performance only, future studies will reflect an evaluation model for the fatigue of marine officers by considering their sleep conditions and workloads and establish a reasonable and reliable evaluation system by accumulating various collision scenarios and by complementing the existing evaluation criteria.

ACKNOWLEDGEMENTS

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

6.7 The effects of causation probability on the ship collision statistics in the Gulf of Finland

M. Hänninen & P. Kujala
Helsinki University of Technology, Helsinki, Finland

ABSTRACT: In this study the marine traffic safety in the Gulf of Finland is studied by examining the collision probability estimates in a heavily used crossing area. In a commonly applied approach for estimating the probability of collision accidents, so-called number of collision candidates is multiplied with a so-called causation probability. In this study a Bayesian network model for the causation probability estimation is applied with different parameter values in order to examine the effects of weather and human factors on collision probability in the crossing of Helsinki-Tallinn traffic and vessels navigating east- or westbound. The results show that the probability of collisions is very sensitive to the causation probability value and it should be modelled with great care to obtain reliable results.

1 INTRODUCTION

The Gulf of Finland is a sensitive geographical area. The Baltic Sea, including the Gulf of Finland, has been categorized as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organization (IMO, 2005). Maritime traffic is continuously increasing in the Gulf of Finland. Especially the increasing number of oil tankers is raising concern in the coastal countries. Russia is building new oil terminals, and the annual oil transports via the Gulf of Finland are estimated to increase even up to 250 millions of tons by 2015 (Finnish Environment Institute 2007). The increasing maritime traffic increases the risks of accidents, which could lead to oil spills. An oil disaster would most probably have serious effects on the Gulf of Finland ecosystem (Ihaksi et al. 2007).

Based on maritime accident statistics, groundings and collisions are the dominant accident types in the Gulf of Finland (Kujala et al. 2009). A commonly applied approach for estimating the probability of collisions or groundings in maritime traffic was defined by Fujii et al. (1971, 1974) and Macduff (1974). In this approach, the number of ships that would collide or run aground, if no evasive manoeuvres are made is calculated first. In the calculations it is assumed that the ships are sailing "blindly" in the waterway. This so-called number of collision candidates depends on the properties of ship traffic such as geometric traffic distribution on the studied waterway and ship sizes and speeds. In order to estimate the potential number of collisions or groundings, the number of collision candidates is then multiplied by the probability of not making evasive manoeuvres, so-called causation probability, which is conditional on the blind navigation assumption. The causation probability thus quantifies the proportion of cases when an accident candidate ends up grounding or colliding with another vessel. This approach for estimating the potential number of collisions or groundings can be expressed as

$$P = N_a \times P_C \qquad (1)$$

where N_a = the number of collision or grounding candidates; and P_C = causation probability, i.e. the probability of not making evasive manoeuvres.

Not making an evasive manoeuvre while being on a collision or grounding course can be a result of a technical failure such as failure of steering system or propulsion machinery, human failure, or environmental factors. Technical failure was reported as the primary reason of the accident in 9.4% of collision and grounding accidents in the Gulf of Finland, and in 25% of the cases the primary reason had been conditions outside the vessel (Kujala et al. 2009). Human failure has been commonly stated as the most typical cause group of marine traffic accidents: different studies have shown that 43%–96% of the accidents had been caused by humans (Grabowski et al. 2000, Hetherington 2006, Rothblum 2006, Kujala et al. 2009).

Causation probability values for crossing encounters in the literature have varied between $6.83 \cdot 10^{-5}$ – $6.00 \cdot 10^{-4}$ (Macduff 1974, Fujii 1983, Fowler & Sørgård 2000, Otto et al. 2002, Rosqvist et al. 2002). The values have been either general values on some sea area, or reflecting certain ship types or conditions. In good visibility within VTS zone, Fowler & Sørgård (2000) estimated a causation probability of $6.83 \cdot 10^{-5}$, and in poor visibility the value was $4.64 \cdot 10^{-4}$. For collisions in the Gulf of Finland within VTS zone where at least one of the colliding vessels was a tanker, Rosqvist et al. (2002) estimated the value to be $5.1–6.0 \cdot 10^{-4}$, depending on the other ship type.

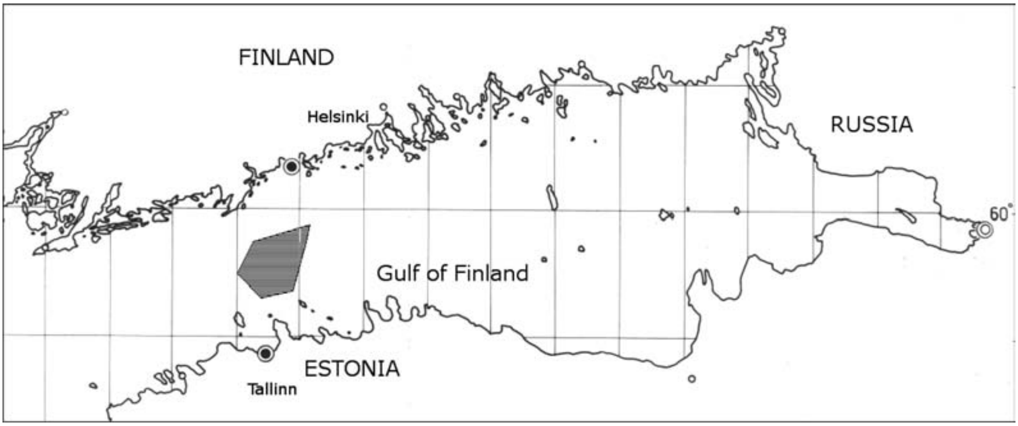

Figure 1. The studied crossing area between Helsinki and Tallinn marked in grey on the map.

In the earliest collision probability estimations the causation probability was estimated based on difference between the registered number of accidents and the estimated number of collision candidates (Fujii 1971, 1974; Macduff 1974). Applying a causation probability value derived from a study in another sea area or estimating it based on the difference in accident statistics and geometrical probability may save some effort, but then the actual elements in accident causation are not addressed at all, as opposed to constructing a model for the estimation. Getting a numerical value for the probability of not making an evasive manoeuvre is only one outcome of a model, the acquired model structure itself and the dependencies of the parameters may be at least equally important.

Risk analysis tools such as fault tree analysis have been used in modelling the causation probability (e.g., Pedersen 1995). In 2006, utilization of Bayesian networks in Step 3 of the Formal Safety Assessment was suggested in a document submitted by the Japanese agency for maritime safety to the IMO Maritime Safety Committee (2006). Bayesian networks are directed acyclic graphs that consist of nodes representing variables and arcs representing the dependencies between variables (e.g. Jensen 2007). Each variable has a finite set of mutually exclusive states. For each variable A with parent nodes $B_1,\ldots, B_n$ there exist a conditional probability table $P(A \mid B_1, \ldots, B_n)$. If variable A has no parents it is linked to unconditional probability P(A). For identifying the relevant nodes and the dependencies between nodes, and constructing the node probability tables, both hard data and expert opinions can be used and mixed. Bayesian networks can also be used as an aid in decision-making under uncertainty. Bayesian networks have been applied in causation probability estimation such as in the maritime traffic risk assessment software GRACAT (Friis-Hansen & Simonsen, 2002) and in Øresund sound risk assessment (Rambøll, 2006).

The study described in this paper is a part of a cross-disciplinary approach for minimising the risks of maritime transport in the Gulf of Finland, where, based on growth predictions, the maritime traffic in the Gulf of Finland in the year 2015 is modelled and the accident risk, the direct environmental effects and the risk of environmental accidents are evaluated, and the effects of national and international legislation and other management actions are modelled (Klemola et al. 2008). In the previous work ship collision probabilities for two locations in the Gulf of Finland were estimated by applying causation probability values derived from literature (Kujala et al. 2009). This paper describes the application of a Bayesian network model for the causation probability modelling as a part of collision probability estimation for the traffic in a crossing area in the Gulf of Finland. The network is utilized for studying the effects of weather, human factors, and extra vigilance on the collision probability.

2 STUDIED AREA: CROSSING BETWEEN HELSINKI AND TALLINN

The studied location (Fig. 1) is one of the highly trafficked crossings of waterways in the Gulf of Finland. In this area the vessel traffic between Helsinki and Tallinn is crossing the main route of the Gulf of Finland, i.e. vessels heading to and from Russia and eastern ports of Finland. Based on AIS records, in July 2006 there had been 2122 ships navigating north- or southbound, majority being fast ferries or passenger ships, and 2303 ships heading to and from eastern part of Gulf of Finland in July 2006 (Kujala et al. 2009). According to accident statistics, one collision of ships had been reported to occur in the area during six year period (Kujala et al. 2009).

3 MODEL USED FOR GEOMETRIC PROBABILITY

The number of collision candidates in the studied area during one summer month was estimated with a model presented by Pedersen (1995), which followed the concept introduced by Fujii (1971). The number of collision candidates in a time period was calculated as

$$N_a = \sum_i \sum_j \iint_{\Omega(z_i,z_j)} \frac{Q_{1i} \cdot Q_{2j}}{V_i^{(1)} \cdot V_j^{(2)}} \cdot f_i^{(1)}(z_i) f_j^{(2)}(z_j) \cdot V_{ij} D_{ij} \, dA \Delta t \quad (2)$$

where N_a = the number of collisions if no evasive manoeuvres were made; i and j = ship classes of the colliding vessels; Q_{1i} = the number of class i vessels at waterway 1 in time unit; Q_{2j} = the number of class j vessels at waterway 2 in time unit; $V_i^{(1)}$ = the average velocity of class i vessels at waterway 1; $V_j^{(2)}$ = the average velocity of class j vessels at waterway 2; $f_i^{(1)}$ = the lateral distribution of traffic in waterway 1; $f_j^{(2)}$ = the lateral distribution of traffic in waterway 2; V_{ij} = the relative velocity of ships depending on velocities and meeting angle; D_{ij} = so-called geometrical collision diameter depending on vessel lengths, beams and velocities; and Δt = time period under review.

The parameters of the collision candidate model were based on analysis of AIS records from the studied area in July 2006. The lateral distributions were approximated with normal distributions whose parameters were based on AIS records. For the calculations the vessels were grouped into five ship classes: passenger ships, cargo vessels, tankers, high speed crafts (HSCs), and other ships. Each class was divided into four size groups: length less than 100 metres, length at least 100 but less than 200 metres, length at least 200 m, and length unknown for which the average values of length and width of the ship class in question were used. The angle between crossing ships had been varying at the crossing point, so the average angle of arrival of each ship class from each approach direction was used in the calculations.

4 MODEL USED FOR CAUSATION PROBABILITY

The applied Bayesian network model for estimating the causation probability, i.e. the probability of not making evasive manoeuvres, was based on fragments of a collision model network in the Formal Safety Assessment of large passenger ships (Det Norske Veritas 2003) and a grounding model in the FSA of ECDIS chart system (Det Norske Veritas 2006). The network estimated the probability of a collision given that two ships were on a collision course, one ship had lost control and the other ship did not give way. The network included parameters related to navigational aids, conditions, safety culture, personnel factors, management factors, other vigilance, and technical reliability. The network reflected the following events for making an evasive manoeuvre while on collision course. At first the Officer On Watch (OOW) had to detect the dangerous situation either visually or with navigational aids. Detection was influenced by parameters related to external and internal conditions as well as attention. After the detection, OOW had to make a correct assessment of the situation, which was influenced by OOW's performance level. Situation might have also been assessed correctly even without OOW's detection if other vigilance such as a pilot or VTS operator was present to detect the danger. If situation was assessed correctly, OOW had to make an avoiding act. If control was lost because of either wrong or no action or steering failure, the collision might have still been avoided if the other ship gave way. The network was modified so that it was suitable to be applied to an analysis including multiple ship types. The network structure can be seen in Figure 2.

Most of the probability values related to the Bayesian network parameters were derived from the original models and had been mostly based on expert judgment. Ship type distributions in the waterways of the studied area were obtained from AIS-data. The probability distributions of "Weather" states were based on Finnish Meteorological Institute's statistics on the average number fog days at Isosaari in July during 1961–2000, the average number of storm days at Finnish sea areas in July during 1990–2008 thinned by the average portion of storm observations from the Gulf of Finland in 2006–2007, and the average number of strong wind days at Isosaari in July during 1961–2000 (Finnish Meteorological Institute, 2008). The daylight distribution describing the probability of a ship navigating in the dark, conditional on ship class, was based on AIS information and sunrise and sunset times at the studied location at 15.7.2006. The probability of "VTS" state "yes" was set to 1.0 because the studied area is monitored by VTS stations.

The effects of conditions outside the vessel and factors related to human performance on collision probability were studied by constructing scenarios describing different environmental conditions and/or factors related to human performance. The states of the nodes, the probability of which was set to 1.0 in the different environmental and human performance conditions are shown in table 1. For example, the environmental conditions were defined as "poor", if all of the following probabilities in the network were equal to 1.0:

– P(Weather = "storm")
– P(Visibility = "<1 nm")
– P(Daylight = "night")

Causation probability was estimated for scenarios where 1) there was no evidence on any of the network parameters; 2) it was known that environmental conditions were "good" and the factors related to human performance were "good"; 2) it was known that environmental conditions were "good" and the factors related to human performance were "poor"; 3) it was known that environmental conditions were "good" but there was no information on other parameters; 4) it was known that environmental conditions were "poor" and the factors related to human performance were

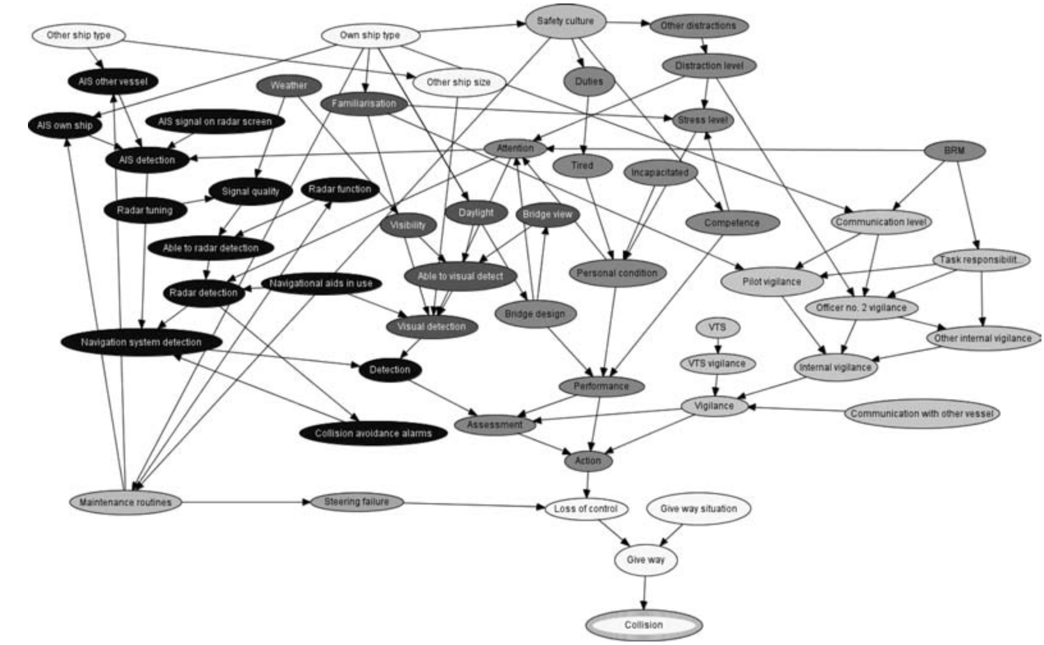

Figure 2. The applied Bayesian network structure for causation probability adapted from (Det Norske Veritas 2003, 2006).

Table 1. Causation probability network node states whose probability were set to 1.0 in good and poor environmental and human performance conditions.

	Environmental conditions		Human performance	
Node	good	poor	good	poor
Daylight	day	night	–	–
Visibility	>1 nm	<1 nm	–	–
Weather	good	storm	–	–
Attention	–	–	high	low
Communication level	–	–	beyond standard	sub-standard
Communication with other vessel	–	–	yes	no
Competence	–	–	high	low
Distraction level	–	–	low	moderate
Duties	–	–	normal	extreme
Stress level	–	–	low	high
Tired	–	–	no	yes

"good"; 5) it was known that environmental conditions were "poor" and the factors related to human performance were "poor"; 6) it was known that that environmental conditions were "poor" but there was no information on other parameters; 7) it was known that the factors related to human performance were "good" but there was no information on other parameters; 8) it was known that the factors related to human performance were "poor" but there was no information on other parameters. In addition, causation probability was estimated for situations where 10) there was no extra vigilance present for detecting the danger; and 11) danger was detected by VTS or other internal vigilance. In situations 10 and 11 there was no evidence on any other parameters than the node "Vigilance". The network was built and the probability calculations were performed with Bayesian network software Hugin.

5 RESULTS OF THE ANALYSIS

General causation probability for the studied location and traffic, meaning that there was no additional knowledge on the network parameters other than the default conditional probabilities of the network, was estimated to be $2.70 \cdot 10^{-4}$. When multiplied by the number of collision candidates, the resulting number of collisions in one month was $1.64 \cdot 10^{-2}$ which equals a return period of 61 months. If it was certain that the danger had been detected by extra vigilance, causation probability estimate was $2.58 \cdot 10^{-4}$ producing return period of 64 months. On the other hand, if there was no extra vigilance, causation probability was $3.74 \cdot 10^{-4}$ and the collision return period decreased to 44 months.

Tables 2 and 3 present causation probability and the expected number of collisions in a month estimates with different environmental and human factor conditions. The lowest collision probability in these scenarios was acquired in good environmental conditions with good human factors, and the collision probability was highest when both the environmental and human factor conditions were poor.

Table 2. Results of causation probability estimation with different scenarios related to environmental and human factor conditions.

Environmental conditions	Human performance		
	Good	Poor	No evidence
Good	2.56E-04	4.27E-04	2.68E-04
Poor	2.94E-04	1.97E-03	7.01E-04
No evidence	2.56E-04	4.44E-04	2.70E-04

Table 3. Estimates of the number of collisions in a month with different scenarios related to environmental and human factor conditions.

Environmental conditions	Human performance		
	Good	Poor	No evidence
Good	1.55E-02	2.59E-02	1.63E-02
Poor	1.78E-02	1.19E-01	4.25E-02
No evidence	1.55E-02	2.69E-02	1.64E-02

6 CONCLUSIONS

The effects of weather and factors related to human performance on the collision probability were studied using a Bayesian network model for estimating the probability on not making an evasive manoeuvre while ships were on a collision course in crossing area between Helsinki and Tallinn in the Gulf of Finland. The general causation probability was estimated to be $2.70 \cdot 10^{-4}$, which is about the same order than the values found in literature. With this causation probability, the return period of collisions in the crossing area between Helsinki and Tallinn was estimated to be 5 years. According to statistics, one collision had occurred in the area in 6 years so it could be stated that the model reflected well the actual situation. However, it should be noted that it is hard to compare the results to statistics since analyzed time interval should be long but the traffic would have to remain constant. The return periods were estimated based on one summer month traffic data. The traffic in the area is very different during in winter period. Thus the effects of winter should also be included in modelling in the future.

According to the applied model, if human performance factors were poor and the ship would be sailing in difficult conditions at dark, the probability of a collision in the studied area would be almost eight times as big as in good environmental and human performance conditions. If just the difference in human performance is examined, the collision probability with poor human performance factors would be almost twice the probability in good human performance conditions. This evaluation shows that the validity of the network parameters is important in order to produce realistic estimates of collision probabilities. In the future expert judgment and ship simulator studies will be utilized in order to validate the model to the traffic and conditions in the Gulf of Finland. With a valid model the effects of possible risk control options on collision probabilities can be evaluated and the model can be used as an aid in decision-making.

All theoretical analysis completed in this document is based on data of only one month, July 2006. The amount of traffic is largely dependent on the season as well. Naturally this also means that the comparison with the accident statistics and theoretical model using only data from one month raises some concerns. This paper can, however, be considered as a good start to more profound analysis of the causation probability in the area, which should be conducted on monthly basis covering the whole year and based on data from other months as well.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

6.8
An influence of the order to maintain minimum distance between successive vessels on the vessel traffic intensity in the narrow fairways

L. Kasyk
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: All vessel traffic regulations disturb the randomness of the vessel traffic stream. In this paper the disturbing factor is the order to maintain minimum distance between successive vessels. The intensity of the disturbed vessel traffic has been determined. To achieve this goal the convolution method has been used. Next the connection between traffic stream parameters and this disturbed intensity has been analysed.

1 INTRODUCTION

1.1 *Narrow fairways*

The vessel traffic on narrow fairways is subject to different restrictions: speed limit, overtaking ban, passing ban and others. When ships must go one by one they must maintain minimum distance between each other. This distance is specific for each basin, for example on the Świnoujście – Szczecin fairway, the minimum distance between successive vessels is equal to 2 cable.

1.2 *Vessel traffic intensity*

The intensity of vessel traffic is measured by a number of vessels passing in a time unit (Jagniszczak & Uchacz 2002, Gucma 2003). When ships report individually and independently of one another, the intensity can be describing by Poisson distribution (Ciletti 1978, Fujii 1977, Montgomery & Runger 1994). In the case when vessel traffic is disturbed, the density can be determined by using the convolution method. In earlier works (Kasyk 2006) author presented solutions of different problems using particular parts of the convolution method. And this paper is the first application of full convolution method worked out by author (Kasyk 2008).

2 DETERMINATION OF INTENSITY

2.1 *Component random variables*

According with the convolutions method (Kasyk 2008, Nowak 2002) it's necessary to isolate particular random variables. The time difference between leavings the fairway section with the disturbance, by successive ships is equal to:

$$DT = X + (Y_B - Y_A) + (W_B - W_A) \tag{1}$$

where X denotes the waiting time for the reporting of the successive fairway unit in none disturbance traffic; Y denotes the time necessary to change of vessel traffic parameters; W is the time necessary to cover the fairway section on which the order to maintain minimum distance between successive vessels exist. The indexes A and B by names of random variables denotes realisations of particular variables for different successive units.

The variable X has an exponential distribution (Ciletti 1978, Fujii 1977, Gucma 2003, Kasyk 2004, Nelson 1995). In this paper the variable Y has a normal distribution (Kasyk 2006). When the ship is forced to sail after the more slowly unit, she must reduce her own speed. The longest time necessary to cover the fairway section on which the order to maintain minimum distance exist is equal to d/v_{av}, where d is the length of this section and v_{av} is the average velocity in this section. While the shortest time of covering this fairway section amounts d/v_{max}, where v_{max} is the highest velocity in this section. On narrow fairways, usually the average velocity doesn't differ much from the maximum velocity. Hence the variable W can be described by an uniform distribution on the interval from d/v_{max} to d/v_{av}.

2.2 *Probability distribution of vessel traffic intensity*

Using all operations of the convolution method (Kasyk 2008), p.d.f. of variable 1/T has been determined. This variable, as the inverse of the time between leavings the fairway section by successive ships, denotes the number of ships leaving the special section in the time unit. This is a continuous variable and its probability density function f(*x*) is given by the form presented below. In this form the function erf(*z*) appears. It is the integral of the Gaussian distribution, given by:

$$\operatorname{erf}(z) = \int_0^z e^{-t^2}\, dt \tag{2}$$

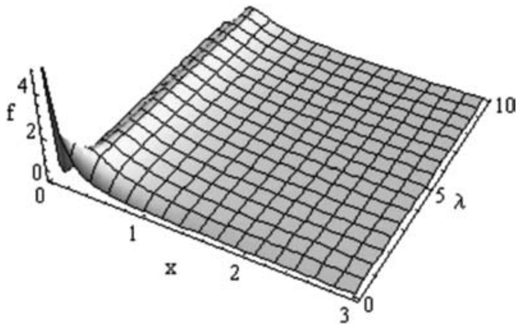

Figure 1. Dependence of function f(x) on parameter λ.

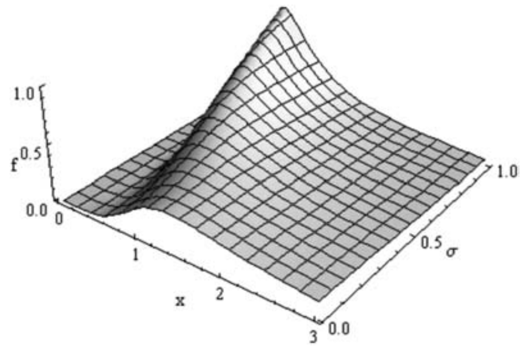

Figure 2. Dependence of function f(x) on parameter σ.

The function erfc(z) is given by: erfc(z) = 1 − erf(z).

$$
\begin{aligned}
f(x) = {} & \frac{1}{2r^2x^2}\left(4r + \frac{4\sigma}{\sqrt{\pi}}\exp\left(\frac{-(xr-1)^2}{4x^2\sigma^2}\right) + \frac{4\sigma}{\sqrt{\pi}}\cdot\right. \\
& \cdot\exp\left(\frac{-(xr+1)^2}{4x^2\sigma^2}\right) - \frac{8\sigma}{\sqrt{\pi}}\exp\left(\frac{-1}{4x^2\sigma^2}\right) - \frac{4}{x}\operatorname{erf}\left(\frac{1}{2\sigma x}\right) + \\
& + 2\left(\frac{1}{x} - r\right)\operatorname{erf}\left(\frac{rx-1}{2\sigma x}\right) - 2\left(\frac{1}{x} + r\right)\operatorname{erfc}\left(\frac{rx+1}{2\sigma x}\right) + \\
& + \frac{1}{\lambda}\exp\left(\lambda^2\sigma^2 - \lambda r - \frac{\lambda}{x}\right)\cdot\left(\exp(2\lambda r)\operatorname{erfc}\left(\frac{rx+2\lambda\sigma^2-1}{2\sigma x}\right) + \right. \\
& + \operatorname{erfc}\left(\frac{2\lambda\sigma^2 - rx - 1}{2\sigma x}\right) + \exp\left(\frac{2\lambda}{x}\right)\operatorname{erfc}\left(\frac{2\lambda\sigma^2 - rx + 1}{2\sigma x}\right) + \\
& + \exp\left(\frac{2\lambda}{x} + 2\lambda r\right)\operatorname{erfc}\left(\frac{2\lambda\sigma^2 + rx + 1}{2\sigma x}\right) - 2\exp(\lambda r)\cdot \\
& \left.\left. \cdot\operatorname{erfc}\left(\lambda\sigma - \frac{1}{2\sigma x}\right) - 2\exp\left(\lambda r + \frac{2\lambda}{x}\right)\operatorname{erfc}\left(\lambda\sigma + \frac{1}{2\sigma x}\right)\right)\right)
\end{aligned}
\tag{3}
$$

Integrating the function f(x) in corresponding limits we obtain the probability mass function of the variable I (the vessel traffic intensity after leaving the fairway section with the order to maintain minimum distance):

$$
P(I = n) = \int_{n-0,5}^{n+0,5} f(x)\,dx \tag{4}
$$

3 ANALYSIS OF DEPENDENCE DENSITY FUNCTION ON TRAFFIC PARAMETERS

3.1 *Traffic parameters*

Function f(x) depends on three parameters: λ, σ and the difference $r = (b - a)$. 1/λ is the mean of the variable X. σ is the standard deviation of the variable Y and the interval $[a, b]$ is the range of the variable W. Figure 1 presents the dependence of f(x) on the parameter λ, with established σ and r.

All parameters have been examined in ranges corresponding with real conditions. Hence r is located between 0.1 hour and 2 hours, σ stays within the range from 0.01 hour to 1 hour and λ is from the interval [0.1/h, 10/h].

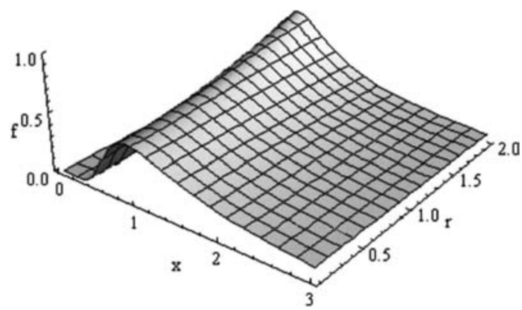

Figure 3. Dependence of function f(x) on parameter r.

Fig. 2 presents the dependence of the function f(x) on the parameter σ, with established λ and r.

Figure 3 presents the dependence of the function f(x) on the parameter r, with established λ and σ.

Function f(x) changes little for different values σ and r (a bit more for σ). With the change of value of λ the function f(x) changes a lot. Especially when λ closes to 0, the curve f(x) has greater values and it has maximum for the argument closer 0.

3.2 *Comparison between disturbed intensity and random intensity*

The vessel traffic intensity on the exit of the fairway section with the order to maintain minimum distance is different than the vessel traffic intensity on the entrance to this section. The greatest differences appear in the case when the exponential distribution parameter has value greater than 1 (the higher value of λ the bigger differences between intensities) and values of parameters σ and r are high (Fig. 4). The closer 0 λ, the less differences between intensities. And when σ and r close to 0, then density function curves of intensities almost coincide (Fig. 5).

In above figures the probability density function of the vessel traffic intensity on the entrance to the fairway section on which the order to maintain minimum

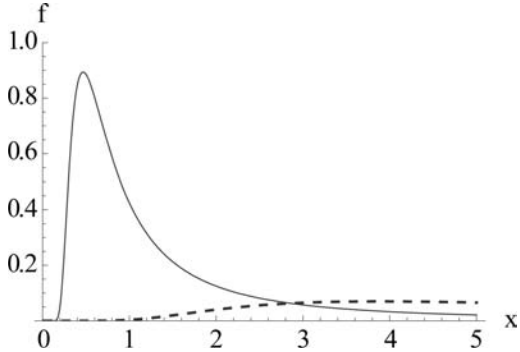

Figure 4. Difference between intensities for large λ.

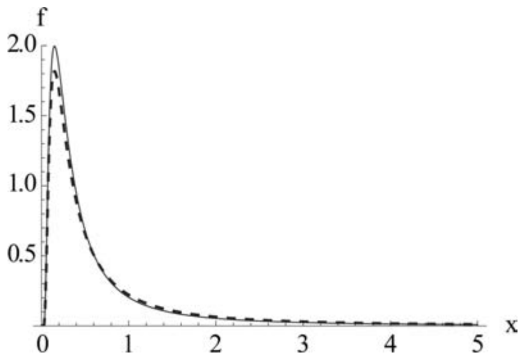

Figure 5. Difference between intensities for λ closing to 0.

distance between successive vessels exist, is marked by dashed line.

3.3 *Extreme case*

In the case, when there are so many ships that they sail one by one with the minimum distance $d_{\min}$ between each other, then the intensity is equal to:

$$I = \frac{d_{\min}}{v_{av}} \cdot \frac{1}{3600s} \tag{5}$$

where d_{min} is expressed in metres; the average vessel speed v_{av} is expressed in metres per second.

4 CONCLUSIONS

Intensity of the disturbed vessel traffic, as a number of reports in a time unit, has been approximated by continuous random variable 1/T. Applying the convolution method the density function of variable 1/T has been determined.

If disturbances in fairway vessel traffic are big (values of parameters σ and r are high), then there are large differences between the vessel traffic intensity on the exit of the fairway section with the order to maintain minimum distance and the vessel traffic intensity on the entrance to this section.

For practical uses, the random variables separated in this model, should be verified with measurements or simulations.

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6.9
On determination of the head-on situation under Rule 14 of COLREG-72

V.M. Bukaty & S.U. Morozova
Baltic Fishing Fleet State Academy, Kaliningrad, Russia

ABSTRACT: Analyzed one possible criteria of stating the fact of ships' meeting on reciprocal courses and proved that none of them can be judged with confidence of head-on situation. So, in fact Rule 14 of COLREG-1972 should be strictly adhered to: "…*When a vessel is in any doubt as to whether such a situation exists we shall assume that it does exist and act accordingly*…", i. e. alter the course to starboard.

1 INTRODUCTION

Rule 14 of International Regulations for Preventing Collisions of Sea-72 applies to the navigation of ships in sight of each other on reciprocal courses, when they are meeting head-on. "…When two power-driven vessels are meeting on reciprocal or nearly reciprocal courses so as to involve risk of collision each shall alter her course to starboard so that each shall pass on the port side of the other…" – this how Rule 14 of COLREG states. It seems to be simple and quite understandable! Statistics of ship collisions, however, shows that regardless of simplicity and clearness of the actions according to this Rule more than 50 percent of collisions precisely occur when vessels are meeting on reciprocal courses (Karapuzov, A. I. & Mironov, A. I. 2005. Maneuvering…). The points that on practice application of Rule 14 becomes complicated as it doesn't give exact quantitative criteria both for definition of "head-on situation" and minimum permissible "collision approach situation" to execute maneuvering safe passing clear of each other. As to the criteria of clearing up head-on situation, Rule 14 contains only the direction that "…Such a situation shall be deemed to exist when a vessel sees the other ahead or nearly ahead and by night she could see the masthead lights of the other in a line or nearly in a line and/or both sidelights and by day she observes the corresponding aspect of the other vessel… When a vessel is in any doubt as to whether such a situation exists, she shall assume that it does exist and act accordingly". The use of such inexact notations as "…nearly reciprocal courses…", "…nearly in a line…", "…nearly ahead…", "…corresponding aspect of the vessel…" as well as the absence of exact quantitative criteria in Rule 14 don't make it possible for navigators to judge the head-on situation in a unique manner. By virtue of navigators' subjective perception of inexact notations, laid in Rule 14, some of them consider the head-on situation as falling under Rule 14, and the others – under Rule 15 applying crossing situation. The lack of agreement in navigators' actions to different Rules

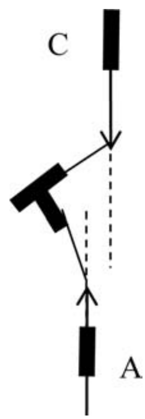

Figure 1. An example of dangerous situation development, when on navigator considers that he acts under Rule 14, and the other – under Rule 15.

of COLREG in the same situation often leads to collisions. It can be illustrated by some simple examples from practice (Snopkov, W. I. 2004. Ships'…). Fig. 1 shows the case in which one of the navigator (navigator C) has determined the situation as "head-on" falling within the jurisdiction of Rule 14 in accordance with which he changed the course to starboard and the other one (navigator A) has determined the situation as "crossing" falling within the jurisdiction of Rule 15 and considered it necessary to keep out of the way of the ship on her own starboard and changed the course to port. Further development of the situation doesn't require any commentaries.

Russian commentaries to COLREG-72 don't at all consider the problem of quantitative criteria as applied to Rule 14, i.e. of minimum permissible aspect of oncoming vessel when it is to be considered as the vessel proceeding on reciprocal course head-on. In Russian commentaries to COLREG-72, complying with Rule 14, it is recommended in any doubt to use

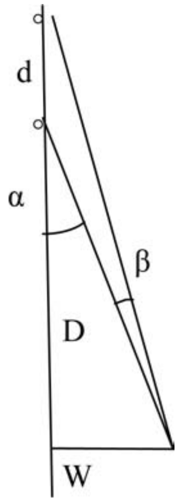

Figure 2. On calculating of angular perceptibility of linear alignment.

Rule 14 for altering the course "ahead of time and positively" to starboard.

Some foreign commentaries to COLREG-72, based on the materials of judicial arbitrary documents, assume that in the same case when the difference in courses doesn't fall outside the limit of 180° ± half a point, Rule 14 shall be applied. If the difference in courses falls outside the limit of 180° ± half a point, Rule 15 is recommended to apply (Karapuzov, A. I. & Mironov, A. I. 2005. Maneuvering…).

2 CLEARING UP THE HEAD-ON SITUATION ACCOUNTING MAST IN LINE

If the vessels are in sight of one another, then in day time a trivial criterion of their meeting on reciprocal courses might be an alignment of the oncoming vessel's masts, that can be seen with unaided eye or through the binocular. In this case let's consider this criterion. An observer is known to think that he is on a line of alignment (Fig. 2) until he deviates from it so that the formed angle a between the directions to leading beacons will not be larger than an angular perceptibility of the observer's eye. Then, Fig. 2 shows, that deviation W from the alignment axis will be (Kolomijchuck. 1975. Hidrography…)

$$W = \frac{D(D+d)}{d}\beta \qquad (1)$$

where d – the distance between leading beacons; D – the distance up to front leading beacons.

This, angle α determining an angular accuracy of the observer position in line will be:

$$tg\alpha = \frac{W}{D}$$

Table 1. Angular accuracy of defining oncoming masts alignment, *degrees*.

Distance between masts *d*, *miles*	Distance up to front mast *D*, *miles*				
	1	2	3	4	5
20	15.2	28.4	39.0	47.2	53.4
40	7.8	15.2	22.1	28.4	34.0
60	5.3	10.3	15.2	19.8	24.2
80	4.0	7.8	11.5	15.2	18.7
100	3.2	6.3	9.3	12.3	15.2
120	2.7	5.3	7.8	10.3	11.0
140	2.4	4.6	6.7	8.9	9.7
160	2.1	4.0	5.9	7.8	8.6
180	1.9	3.6	5.3	7.0	8.6
200	1.7	3.2	4.8	6.3	7.8

Or in view of (1) and accepting for an unaided eye of the observer that $\beta = \varepsilon = 1'$ we record in writing

$$\alpha = arctg(\frac{D+d}{d} arc1') \qquad (2)$$

According to (2) with the oncoming vessel's masts displacement equals 100 m, at a distance $D = 4$ miles, we receive $\alpha = 12.3°$. For other values of d and D, the meanings of angle α are given in Table 1. As the table shows, to detect the movement of oncoming vessel proceeding on reciprocal course head-on by its masts alignment with unaided eye practically impossible. This is true even for very large vessels at close quarter distance as well. At least the accuracy to establish such fact will contradict with the accuracy the modern course indicatory can provide. The observer will assume that the vessels are proceeding on reciprocal courses head-on, though in reality their courses can differ by some degrees and even by some ten degrees (as to small ships they can be at a considerable distance from the observer). Probably, half a point difference in opposite courses, considering as a criterion for ships in head-on situation in the Foreign Commentaries to Rule 14, as it was mentioned above, when observing with an unaided eye is related to meeting distance in 1–2 miles with masts displacement of the oncoming ship by a factor of 60–120 m., as Table 1 shows. But they are closest point of approach close to last moment distances for maneuvering.

Using a binocular or optical finding tube for observation can help to improve the situation and increase the eye resolution (in our case to increase angle β) in numbers equal to multiplicity of a binocular and finding tube increase (Kolomiychuck. 1975. Hidrography…). But even if angle β is reduced by a factor of 10 it will means according to (2), that the angular accuracy of defining masts alignment is increased by a factor of 10, as Table 1 shows. But it doesn't solve the problem of small-sized vessels neither in the maneuvering zone (distance of 4–8 miles), nor in all the distances of close quarter (distance of 4 miles), to say nothing of the distances in the zone of situation

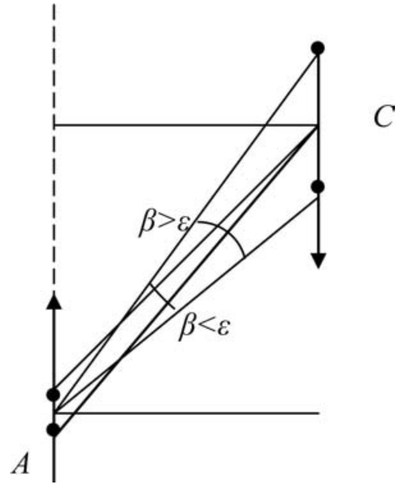

Figure 3. A navigator of small ship *A* sees the masts a large ship *C* not in line, and he think the ships are proceeding on reciprocal courses, and a navigator of large ship *C* sees the masts of small ship *A* in line and he thinks the ships are proceeding head-on.

appraisal (8–12 miles). As a result, the following situation is possible (Fig. 3): the navigator of a large ship observing the masts alignment of the oncoming small ship has come to the conclusion that it is proceeding on a reciprocal course head-on ($\beta < \varepsilon$) and decided to act according to Rule 14, altering the course to starboard. The navigator of a small ship, who has had the possibility to determine the masts alignment of a large ship, come to the conclusion that the masts of an oncoming ship are not in line ($\beta > \varepsilon$) and, accordingly, the ships are proceeding on reciprocal courses and he decided to take head-on maneuvering under Rule 15, altering the course to port and keeping out of the way of the ship on his own starboard. As a result, there was a situation schematically presented on (Fig. 1).

3 CLEARING UP THE HEAD-ON SITUATION ACCOUNTING MASTHEAD LIGHTS AND SIDELIGHTS

By night time the criteria for ships in head-on situation could be simultaneous visibility of sidelights or masthead lights in line. As to the criterion of determining head-on situation by the alignment of masthead lights, it is evidently that it is not better than the criterion of determining head-on situation by the alignment of the masts. Both of them have the same shortcomings. As to the criterion of clearing up the head-on situation by the visibility of sidelights, in our opinion, thought it is not perfect, it has some advantages in comparison with the criteria of clearing up the head-on situation by alignments of masts or masthead lights. The point is that in compliance with Rule 21 to COLREG-72 "… Each sidelight shows an unbroken light over an arc of the horizon of 112.5° and so fixed as to show the light from right ahead to 22.5° abaft the beam on its respective side. In Annex 1 to COLREG-72 it is defined more exactly that." In the forward direction, sidelights as fitted on the vessel shall show the minimum required intensities. The intensities must decrease to reach practical cut-off between 1 degree and 3 degrees outside the prescribed sectors." It means that having difference up to $180 \pm 3°$ in "nearly reciprocal courses" approaching vessels can observe the sidelights of one another: it will seem to them that they are proceeding on opposite courses, i.e. head-on. The same situation can arise when two ships are approaching each other "not head-on", but on opposite course (parallel course), in the case, when the course angle of observed ship in visibility of sidelights (3 miles) has the meaning up to 3°, i.e. when the distance between course lines is about 1,5 cables and there will arise the risk of collision because of the hydrodynamic interactions of the ships. These circumstances could have been taken as more precise definition of the notation "nearly reciprocal courses". They are supposed to be the courses, the differences of which, is within the limit of $180 \pm 3°$. However, the substantial limitation, of criterion of the determination of head-on situation by the visibility of both sidelights is that it can be only applied at small distances between the ships because of their poor visibility.

As applied to clearing up the quantitative criteria of meeting of the ships proceeding on reciprocal (nearly reciprocal) courses head-on, we have put a special emphasis on the fact that the above-mentioned criteria could have been the same, that is they could have been implemented only under perfect conditions of navigation, when no external factors influence upon ships' movement and when the ships could have been able to proceed without drifting and sheering along the course line (Fig. 1, Fig. 2). But the case it not often like this.

In practice in most cases of ship's navigation, any ship is exposed to winds and currents, and because of that, first the ship, is moving with drift angle, that is, not along the course line but on track line and, second, the ship lab ours yawing. As a result, the ships can move head-on (move on reciprocal track lines), though their courses difference can be other than 180°. Moreover, due to yawing it can be alternating, either larger or smaller than 180°. By daytime for the same reason, masts alignment of oncoming chip can't be observed, they can be either aligned or not aligned, and at night time only one sidelight can be observed – if the ship is moving with constant drift angle and both sidelights can casually appear – if the ship is moving with yawing (Fig. 4).

In case, ships are proceeding with drift angle, it would be correctly to say, in our opinion that they are meeting on reciprocal track angle.

4 CLEARING UP THE HEAD-ON SITUATION WHEN USING RADAR

If the ships are proceeding with visual drift angle, instantaneously received criterion for clearing up head-on situation is not perceived at all. The only

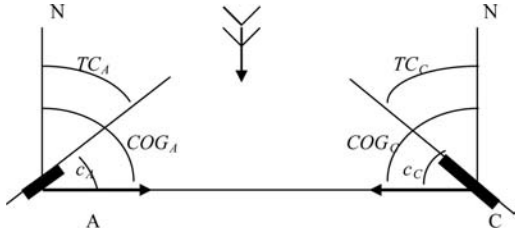

Figure 4. Ships proceeding on reciprocal course.

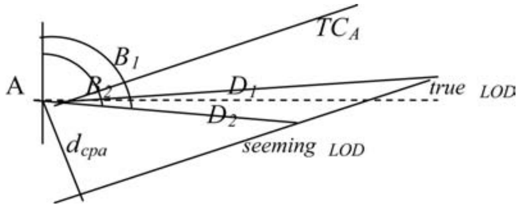

Figure 5. Possible result of relative plotting aboard A ship, when ships are proceeding on reciprocal track angles. The result was caused by random error in taking bearing.

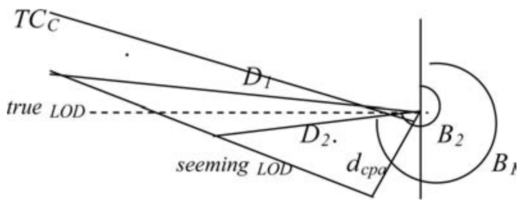

Figure 6. Possible result of relative plotting aboard B ship, when ships are proceeding on reciprocal track angles. The result was caused by random error in taking bearing closest point of approach.

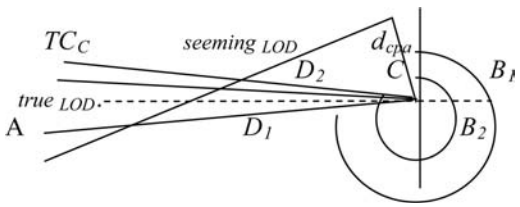

Figure 7. Possible result of the plotting on C ship when two ships are proceeding on reciprocal track angles. The result was caused by random errors in taking bearings.

things to be undertaken in this case is to solve this problem in classic way, i.e. by relative plot ling method, observing the oncoming ship's alignment changes and distance to it by the radar. However, it should be implied that the question is about ships movement on nearly reciprocal route angles with relatively small course angles of each other and nearly equals to drift angle. That's why occasional errors of measuring, especially of bearings will greatly influence upon the results of relative plotting. Really, assume that the ships are preceding at speed of 10 knots on reciprocal courses with track angles and at a distance of 5 miles the navigators, observing with binocular or through optical finding tube, sight masthead lights supposedly not in line. In fact, it could be true, as under the condition of the problem, the ships are proceeding with drift angle. The navigator of A ship thinks that C ship is on his starboard side, and the navigator of C ship think, that A ship is on his portside. Nevertheless, the navigator of A ship decided to define more exactly head-on situation and he measured the bearing of C ship and distance to it by radar, and three minutes later he repeated his measuring again. Under the condition of a problem the C ship's bearing must not change, but due to occasional errors of gyrocompass (and with probability of 95% they can reach values $\pm 0{,}5^\circ$ (Directions on…1987) it turned out that at a distance $D_1 = 5$ miles, bearing B_1 was $89{,}5^\circ$ in the first measuring, and in the second measuring at a distance $D_2 = 4$ miles bearing was $B_2 = 90{,}5^\circ$. Calculation of closest point of approach by a formula:

$$d_{cpa} = \frac{D_1 D_2 \Delta B}{\Delta D} \qquad (3)$$

where $\Delta B = B_2 - B_1$, $\Delta D = D_2 - D_1$, which gives it accurate to the component of 2nd order infinitesimal with minor values d_{cpa} (Luschnikov, E. M. 2007. Ships'…), and also relative plotting "made sure" the navigator of A ship that C ship would be on his reciprocal, but parallel course and pass his starboard at a closest point of approach (CPA) $d_{cpa} = 3.5$ cables (Fig. 5). It is not excluded, that the navigator of C ship also observed distance and bearings changes of A ship and his results were that at a distance of 5 miles A ship's bearing was equal to $270{,}5^\circ$ and at a distance of 4 miles it was equal to 269°, though, in fact A ship's bearing did not change and was equal to 270°. As a result of relative plotting and the above occasional errors in taking bearing, he "cleared up" that A ship was proceeding reciprocal but parallel course and it would pass on his port side at a close quarter distance of 3.5 cables sufficient for safe passing (Fig. 6). Both navigators could regard that ships would pass at a sufficient distance, but actually they were proceeding reciprocal track angles head-on.

We cannot ignore one more situation, under which radar observation aboard A ship has showed that at a distance of 5 miles A ship's bearing is equal to 269.5°, and at a distance of 4 miles it has changed to 270.5°. In that case a relative plotting showed that A ship was crossing C ship's course and would pass it at a closest point of approach of 3.5 cables (Fig. 7). A ship's navigator thinking that both ships, even if they are proceeding on reciprocal parallel courses, but at a short distance of closest point of approach d_{cpa}, and taking into consideration small bearing changes of C ship (even 1° is a sign of risk of collision) has decided to act in compliance with Rule 14, altering course to starboard. But C ship's navigator, computing the situation of meeting on crossing courses and A ship as being on his starboard has decided to act in compliance with Rule 15 and keeping out of the way of A ship, turned port side and as a result the situation of meeting has arisen which could lead to ships' collision of which we have mentioned earlier (Fig. 1).

Thus, we have made sure that neither visual nor radar observation permit to determine with confidence the fact of ships' approaching on reciprocal courses (with track angles). That's why in this case of uncertainty, for want of something better, we should comply with Rule 14 of COLREG : "…When a vessel is in any doubt as to whether such a situation exists she shall assume that it does exist and acts accordingly…", i.e. alter course to starboard in due time. But the whole problem lies in that every navigator has his own degree of doubt…

5 CLEARING UP THE HEAD-ON SITUATION WHEN USING AUTOMATIC IDENTIFICATION SYSTEM

During the past few years many ships are being equipped with new technical aids to navigator, in particular, automatic information systems (AIS). They allow the ships' meeting within the range of VHF coastal station (about 20 miles) to exchange information about current positions of the ships, their speed, track angles, etc. That's why it is interesting to clear up their capabilities in order to determine head-on situations.

Ships' coordinates related to the same time and received from AIS allow determining the distance between ships and an oncoming vessel's bearing. Actually, if at some instant of time t_1 we received coordinates ϕ_{o1} and λ_{o1} of our ship and coordinates ϕ_{b2} and λ_{b2} of the oncoming vessel, distances D_1 and D_2 between ships and the oncoming vessel's bearings B_1 and B_2 at those instants of time can be determined by formulae:

$$D_1 = \sqrt{(\varphi_{o1} - \varphi_{b1})^2 + (\lambda_{o1} - \lambda_{b1})^2 \cos^2 \varphi_m} \tag{4}$$

$$B_1 = arctg \frac{(\lambda_{o1} - \lambda_{b1}) \cos \varphi_m}{\varphi_{o1} - \varphi_{b1}} \tag{5}$$

$$D_2 = \sqrt{(\varphi_{o2} - \varphi_{b2})^2 + (\lambda_{o2} - \lambda_{b2})^2 \cos^2 \varphi_m} \tag{6}$$

$$B_2 = arctg \frac{(\lambda_{o2} - \lambda_{b2}) \cos \varphi_m}{\varphi_{o2} - \varphi_{o2}} \tag{7}$$

where ϕ_m – an average latitude between vessels.

To simplify these judgments, assume, that navigator takes place near Equator and $\varphi_m = 0$. In this case difference of distances and difference of bearings are:

$$\Delta D = \sqrt{(\varphi_{o1} - \varphi_{b1})^2 + (\lambda_{o1} - \lambda_{b1})^2} - \sqrt{(\varphi_{o2} - \varphi_{b2})^2 + (\lambda_{o2} - \lambda_{b2})^2} \tag{8}$$

$$\Delta B = arctg \frac{(\lambda_{o2} - \lambda_{b2})}{\varphi_{o2} - \varphi_{o2}} - arctg \frac{(\lambda_{o1} - \lambda_{b1})}{\varphi_{o1} - \varphi_{b1}} \tag{9}$$

Knowing the difference of distances and difference of bearings and taking info account the most interesting for practice the occurrence of small distances of close quarter approaching of ships we can use formula (3), to find the distance of close quarter approaching or we can determine it using method of relative plotting.

Root-mean-square errors of distances measuring m_D and measuring of bearings m_B can be found by formulae, following from equations (6) and (7) (Bukaty, V. M. 2005. Research…)

$$m_D = m_{\varphi\lambda} \sqrt{2} \tag{10}$$

$$m_B = \frac{m_{\varphi\lambda} \sqrt{2}}{D} \tag{11}$$

where $m_{\varphi\lambda}$ – a root-mean-square error of determining ships' coordinates (the errors is considered to be identical by latitude and longitude).

For larger simplicity of judgment, assume, the ship are approaching one another meridian so that longitudes difference will equal 0° and latitudes difference at the instant of time t_1, will be 5′. Assume, that at the instant of time t_2 it will be 4′, i.e. at the instant of time t_1 the distances between ships are 5 miles and at some instant of time t_2 – 4 miles. Distances difference is 1 mile. Taking into account that AIS transmits the positions received from receiver-indicator NSS we calculate root-mean-square errors of determining distances and bearings by formulae (10) and (11). Assume NSS is working in the usual condition. Root-mean-square coordinates errors are a factor of $m_{\varphi\lambda} = \pm 20–25$ m, and double errors (with probability 95%) will be a factor of ±40–50 m (IMO Resolution A.953(23). 2003). According to (10) and (11) at instant of time t_1 with probability of 95% distance error between ships is ±0.5°, and error of oncoming ship's bearing is ±0.44°. At instant of time t_2 the error of bearing determination is ±0.55°, and the error of distance determination is just the same. The errors of distance determination as above indicated are not great and they may be ignored. But the point is that bearings defining within the distances of maneuvering zone end practically the same whether we use AIS or radar observation. The relative plotting may show the same results and the same situations of approaching ships as we have considered above when writing about radar observations.

If necessary to consider an example when the distance differences between ships at the time of measuring is equal to 2 miles (measures are being done every 6 minutes at the same ships' speed), then for the distance of 5 miles (1st measure) the error of bearing measuring would be the same ±0.44°, and for the distance of 3 miles (2nd measure) it would be ±0.73° according to (11). It won't improve the situation, more than likely; deteriorate it i.e. the seeming approaching situation might happen not to be in accordance with the truth. In this example AIS fails to gain even to radar observation, where the error of taking bearing can be considered as independent of distances between ships.

It is of interest to examine AIS scope for much earlier ships' approaching situation. Suppose, that under the conditions of previous example ships started using the information of AIS at a distance of 20 miles. It means the errors of distance determination will not be changed and can as before be ignored because of their infinitesimal, and errors of bearing determination will reduce to one-quarter, adding a factor of $\pm 0.1°$ according to (11). But, in spite of the above, owing to distances increasing to one-fourth, closest point of approach will increase being equal to 6.6 cables as to (3). Owing to random errors of taking bearings we, as a matter of fact, receive the same variants of approaching situation from AIS, as we have considered them from radar observations.

Thus, the use of AIS, taking positions from SNS, funning in operation condition in order to clear up the situation when ships are meeting on nearly reciprocal courses cannot solve the problem. And we can repeat again and again the recommendations of Rule 14 that when the vessels are meeting on nearly reciprocal courses and if there is any doubt as to whether such a situation exists we shall assume that it does exists and other the course to starboard in due time.

If the information is entered into AIS from NSS, running in differential condition, the random error of ships' positions with arability of 95% could be taken as equal to 10 m (IMO Assembly Resolution. 2003). Here according to (11) root-mean-square of bearing error will equal to $\pm 0.1°$ when the distance between ships is 5 miles and about $\pm 0.25°$ when the distance is 20 miles.

6 CONCLUSION

Correspondingly, closest point of approach at the same distance difference of 1 mile, as in previous examples, will be equal to 0.7 cables in the first case and 3.3 cables in second one according to (3). Such a small closest point of approach of 5 miles at a starting distance would indoubtly indicate that the ships are meeting on reciprocal course (head-on situation). At a starting distance when the ships are 20 miles apart and the information about ships' position is entered info AIS from NSS, operating in differential condition, a seeming closest point of approach (3.3 cable) is such that it is able to lead a navigator into error as to the approaching situation. Thus, AIS, having received ships' positions from NSS, operating in the differential condition, allow a navigator to make proper judgment about the ships' meeting on reciprocal courses even at such a small distance difference between them at the time of measuring as 1 mile.

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Chapter 7. Communication at Sea

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7.1 Maritime communication to support safe navigation

K.E. Fjørtoft, B. Kvamstad & F. Bekkadal
MARINTEK e-Maritime, Trondheim, Norway

ABSTRACT: The main objectives of the MarCom project ('Maritime Communications – broadband at sea') are to investigate the main user needs and communication technologies requirements to accommodate those needs within the maritime community. The project will carry out several pilots to demonstrate the usability of terrestrial wireless technologies in combination with, and in some areas instead of satellite communication (SatCom). The major benefit to the maritime users are expected to be reduced costs, increased bandwidth, Quality-of-Service (QoS) and improved communication security and versatility.

The MarCom approach is characterized by combining thorough investigations of present and future user needs through nine scenarios/user cases along with identification of cost-effective communication platforms to match the application requirements being obtained. The MarCom investigations have revealed the bandwidth needs for a set of application groups, and identified the data integrity requirements for each group.

Furthermore this paper is addressing the MarCom work with the IMO/IALA e-Navigation strategic initiative in establishing the bandwidth requirements to obtain the major objectives of the e-Navigation concept.

1 INTRODUCTION

MarCom has performed scenario studies in a total of nine different user cases covering nine different focus areas. The case studies have resulted in a total of eight application groups comprising emergency messaging, reporting, technical maintenance, safety and monitoring, infotainment and special purpose applications, as illustrated in Figure 1.

A summary of the capacity requirements revealed in the MarCom case analysis is presented in figure 2. The figure shows the bandwidth needs along the ordinate axes and integrity requirements along the abscissa. Integrity is the reliability of the communication channel, i.e is the assurance that the transferred data is consistent and correct, which is reflecting the QoS requirements pertaining to the application group. As can be seen, the requirements vary from a few bytes to be transmitted for operational management below 10 kbps, to data packages of sizes of above 100 Mbytes for special purpose applications (such as e.g for complex offshore operations).

One of the important objectives of e-Navigation is to improve the communication between ships, as well as between ship and shore. The International Maritime Organization (IMO) has described e-Navigation as; '*the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance*

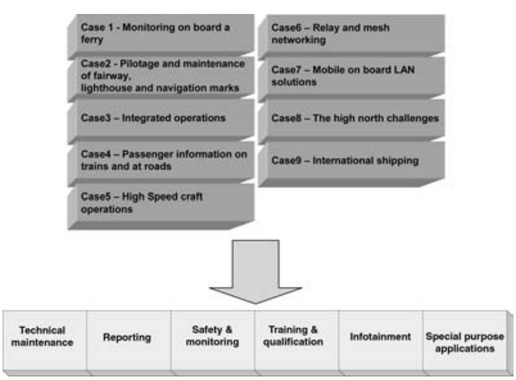


Figure 1. Application groups resulting from the case studies.

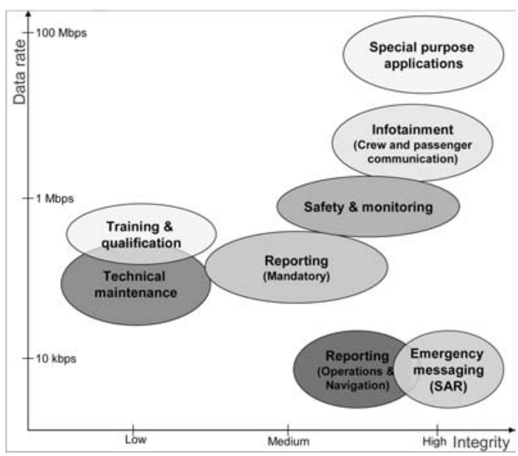


Figure 2. Capacity versus integrity requirements.

berth to berth navigation and related services, for safety and security at sea and protection of the marine environment'.

In MarCom we have studied these objectives by introducing them in the scenarios where both user applications and technology have been addressed.

In the following chapter some of the findings from MarCom in relation to the e-Navigation objectives of IMO are described.

2 MARCOM VERSUS E-NAVIGATION

The following paragraphs are listing the core objectives of the e-Navigation concept defined by the IMO[i]. Within each topic we have listed the MarCom results accordingly along with some conclusions based on the experiences gained from MarCom.

The applications derived from the case studies have been analysed with regards to opportunities and challenges, categorized as:

- *Pain*: What are the problems and challenges within the application groups today?
- *Vision*: How would the applications appear without the existence of the above mentioned pains?
- *Value*: What is the human-related or cost benefit of finding a solution?
- *Power*: Who should be involved to be able to find a solution to the pains?

As an example the '*reporting*' application group has been studied comprising four different reporting sub-groups having been identified as relevant for the MarCom project:

1. Operational Reporting, including route information, cargo information, number of passengers, cash register reserves, deviation reports, travel invoices and HMS reports.
2. Navigational Reporting, including position reports, aids to navigation (AtoN), meteorological and hydrological reporting, and status on fairway objects
3. Technical Reporting, including reports on tank reserves, status reports on technical equipment, reporting between systems and sensors, and cargo reporting
4. Mandatory Reporting, including reporting to port and government, ISPS, classification, and environmental monitoring

Group 1 and 2, operational and navigational reporting requires higher integrity than the two others since it is critical to safe operations.

Examples on different observations have been described in detail, such as for example the *cash register reserves* in group *operational reporting,* where they have been studied in accordance with the four above mentioned issues; a *pain* observation is that the cash register services have to be online to validate the different cards used in a transaction. The *visions* is that the there will be no transaction and verification delay on the different credit cards used as payment. *Value* is that better QoS provided by a high-speed network gives correct validation of a money transaction and can thereby validate potential money transfer without account settlement. Finally the *power* to handle these challenges can comprise the providers of infrastructure (data transmission, service providers, LAN solutions, terrestrial to satellite solutions), the cash register software developers, and the end users.

For each group we have analysed the requirements from a technological and human (user) point of view. This has given us the understanding of future applications and technological needs that have been defining the requirements of communication solutions.

In the MarCom project we have then analysing the findings with reference to the IMO e-Navigation objectives of being listed in the following paragraphs.

2.1 *IMO e-Navigation objective: 'Facilitate communications, including data exchange, among ship to ship, ship to shore, shore to ship, shore to shore and other users'*

The need for transfer of data from a ship to shore is considerable. Previous studies have shown examples that a ship sailing from a foreign port has to send mandatory information to governmental bodies more than 40 times during a voyage[ii]. In addition is the commercial reporting and monitoring (to cargo owners or system equipment providers, with information about technical status on equipment as well as on the cargo), and the communication between the shipping company and the ship.

In MarCom we have mainly focused the communication between ships and shore, but some communication onboard the ship has also been paid attention to.

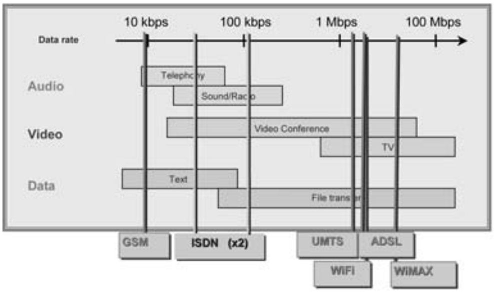
The upper part of Figure 3 shows some telecom services and bandwidth requirements for terrestrial systems that have been studied in view of the applications described, while the matrix in the bottom part is pertaining to services offered by different SatCom systems to accommodate these capacity requirements.

However, since MarCom's foremost technological objective is to extend the coverage and range at sea for both in-use and novel terrestrial wireless systems and technologies, these solutions have been given priority to SatComs.

One of the user cases, *relay and mesh networking*, has taken this a step further within the communication aspect of terrestrial systems, having studied solutions for mesh networking, i.e. networks where the available nodes in an area can be used to relay data, and thus increase the communication range and area coverage. This case comprises technology demonstrations aiming at coverage area extension and

[i] IMO – Sub-Committee on Safety of Navigation (NAV), 53rd session: 23–27 July 2007

[ii] Source; The EU-project MarNIS and the Norwegian project VITSAR



	Inmarsat-A	Inmarsat-B	Inmarsat mini-M	Inmarsat-C	Inmarsat mini-C	Inmarsat Fleet 77	Inmarsat Fleet 55	Inmarsat Fleet 33	Inmarsat GAN	Inmarsat RBGAN	Iridium	VSAT Services
Voice	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Telex	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	Yes
Fax	Up to 9.6 kbit/s	9.6 kbit/s	2.4 kbit/s	Mobile to Fixed only	Mobile to Fixed only	9.6 kbit/s	9.6 kbit/s	9.6 kbit/s	2.4 kbit/s	No	No	Yes
Data	Up to 9.6 kbit/s	9.6 kbit/s or with HSD 64/56 kbit/s (ISDN)	2.4 kbit/s	600 bit/s	600 bit/s	64/56 kbit/s ISDN and 64 kbit/s MPDS (packet switched)	64/56 kbit/s ISDN and 64 kbit/s MPDS (packet switched)	9.6 kbit/s 64 kbit/s MPDS to Fleet 33 28.8 kbit/s MPDS from Fleet 33	64/56 kbit/s ISDN and 64 kbit/s MPDS (packet switched)	Up to 144 kbit/s based on IP	2.4 kbit/s	4.8 kb up to 2 Mb Two way 4.8 kb up to 34 Mb Broadcast
Internet E-mail	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Communications	Real–time	Real–time	Real–time	Store & Forward	Store & Forward	Real–time	Real-time	Real-time	Real-time	High speed access	Real-time	Real – time
Transmission	Analogue	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital
Terminal weight	50 kg	25 kg	2.5 kg	5 kg	1.1 kg	5 kg	3 kg	1.5 kg	4 kg	1.6 kg	0.5 kg	-
Antenna type	Directional	Directional	Directional	Omni-directional	Omni-directional	Directional	Directional	Directional	Directional	Directional	Omni-directional	Directional
Coverage	AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	Spot beams in AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	Global voice, spot beam data in AOR-E/W, IOR, POR	Global voice, spot beam data in AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	Thuraya satellite coverage (North/Central Africa, Middle East & Europe)	Global, incl. the poles	AOR, IOR, POR
GMDSS approved	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No

AOR: Atlantic Ocean Region
IOR: Indian Ocean Region
POR: Pacific Ocean Region

Figure 3. Basic telecom services and bandwidth requirements.

flexibility enhancement by applying a system enabling mobile stations to communicate with a base station through intermediate relay units. The focus is on handover challenges, as well as the mixture of fixed and mobile nodes interconnected via wireless links to form a multi-hop ad-hoc network amongst ships, marine beacons and buoys.

The experiences gained in MarCom have been that we must utilize different communication channels and we need to be able to switch between the different channels. The handover mechanisms between the channels as well as between the base stations must be developed such that the user feel they have a secured link without need of new identification when switching sources or base stations. It would also be beneficial to combine up- and downlinks from different systems, an example being that one channel can be used for uplink, e.g. UMTS, and another for downlink, e.g. WiMAX. It is also important to prioritise those application groups that need high integrity to ensure safe transmission of data. This requirements lead to the need for an intelligent router on the ship to poll and switch between the pertinent systems, which is part of the MarCom work.

2.2 *IMO e-Navigation objective: 'Facilitate safe and secure navigation of vessels having regard to hydrographic, meteorological and navigational information and risks'*

These e-Navigation requirements have been linked to the reporting application group in MarCom. There are different needs on the update frequency of data, from time-critical data for navigational purposes like updates on the traffic situation in the ship's vicinity, to data used for a planning purpose that not are time-critical. Meteorological data is mostly needed on a planning level and can be used within a longer time-frame. However, the information to nautical operators, the status on navigational objects like lighthouses and buoys or other navigational marks, has been placed in the "reporting operations and navigation" application group, where the data integrity is high.

The MarCom studies have concluded that the bandwidth needed for meteorological and hydrographic data is high, but the service required is not time-critical. Regarding information on dynamic objects such as other ships in a fairway, the updating frequency needs to be higher. The information in this group must in any case be regarded as a substitute to a safe navigational operation, and thus merely as a substitute to the navigational personnel.

2.3 *IMO e-Navigation objective: 'Facilitate vessel traffic observation and management from shore/coastal facilities, where appropriate'*

One of the case studies in MarCom is pilotage and maintenance of fairways that has been lead by the Norwegian Coastal Administration. The focus has been to provide the sailors with real-time navigational information, on e.g. the status of navigational objects. The work has been done in two steps; firstly collecting the status from the Coastal Administration (technical maintenances of the navigation objects), and subsequently sending the information to the ships' navigators.

Based on the studies in MarCom, it can be shown that the bandwidth needed for monitoring of a ship position by use of AIS is low. Another conclusion is that one of the communication challenges is to transfer data from e.g. VTS centre ashore to the ship. The integrity classification on the data is high since it is used for navigational purposes.

2.4 *IMO e-Navigation objective: 'Provide opportunities for improving the efficiency of transport and logistics'*

One of the major challenges in ship operations is to make the correct decisions at the correct time. It is a serious problem having to rely on old or maybe wrong data when an operational planning is done. The focus on the problem is highly prioritised in the oil and gas industry where Integrated Operations (IO) should allegedly be one of the beneficial mechanisms in providing efficient and controlled logistical planning processes. It is stated by The Norwegian Oil Industry Association (OLF)[iii] that there is a potential for saving yearly up to 300 billion NOK if the use of

[iii] OLF The Norwegian Oil Industry Association

Integrated Operations can be fully developed[iv] in the Norwegian oil sector. Integrated Operations focuses on how to share data and information between the involved partners to be able to have the same overview, and thereby being in a better position to make, appropriate decisions for correct operations.

Integrated Operations will be one of the demonstration pilots in MarCom, and we are aiming at testing out some of the applications that have been identified in the case studies, where the focus will be on utilizing different technological communication solutions. The bandwidths needed for Integrated Operations are very high due to the use of pictures, sound and video being essential for its success. This requires communication technologies that can handle data rates at least up to around 20 Mbps.

MarCom will test different communication solutions and perform radio channel sounding measurements at appropriate frequencies in some sectors in order to identify capacity and range performance. One of the challenges regarding maritime communication is the radio propagation over sea, low elevation angles, and the roll and pitch movements of both a base station placed offshore, as well as at the mobile station on e.g. a ship. In MarCom we will perform studies on these topics and will real on-site measurements on the pertinent frequencies for wireless systems. We expect the availability of higher bandwidths to provide more efficient operations regarding the transport segment.

2.5 *IMO e-Navigation objective: 'Support the effective operation of contingency response, and search and rescue services'*

There are no specific applications in MarCom directly addressing this topic regarding contingency planning and response, but some defined cases have addressed the topic on safety and monitoring as well as emergency reporting. One of the cases has focused upon the relay and mesh networking to be used in a search and rescue operation. The idea is to build an ad-hoc network around the accident location to support data transmission in an operation. Another case has focused on presenting real status of the fairway objects to be used both for maintenance planning as well as data transfer to ships sailing in a fairway.

Based on the comments and experiences from the case studies in MarCom we can see that one of the problems in an emergency situation is the enormous pressure from media and outsiders to get information from a catastrophic situation, like a ship accident. This requires a lot of bandwidth to transfer data, which is in some cases taken from the available channels used by the rescue team or from those that are handling the accident directly. MarCom will strongly recommend that applications used in search and rescue (SAR) operations must be prioritized, preferably via an exclusively dedicated channel, such that the best channel and bandwidth available can be used by those needing it most.

2.6 *IMO e-navigation objectives: 'Demonstrate defined levels of accuracy, integrity and continuity appropriate to safety-critical system'*

The challenge having been addressed in MarCom is to define which application groups require high integrity that must be absolutely reliable with regards to safety-critical operations. On the opposite we have the training and qualification applications that are not critical to safe operations, and are classified as nice-to-have, and hence have low integrity requirements. The application groups defined in the project will be further developed and demonstrated in the pilots.

The e-Navigation objectives described above will be of high importance to the MarCom project. We are demonstrating effective operation of contingency response, and efficient SAR services are facilitated by technological possibilities for communication. In MarCom we have defined this as most critical application group, and thus subject to a very high integrity level.

2.7 *IMO e-navigation objectives: 'Integrate and present information onboard and ashore through a human interface which maximizes navigational safety benefits and minimizes any risks of confusion or misinterpretation on the part of the user'*

One of the problems with presenting critical information in an unwanted situation is that this information can be used juridical against the source of it. For example if the captain or the safety officer on a ship are guiding the passengers in a non-optimum direction during an emergency situation, this can be used against them at a later stage. Similar situations can also arise in provision of navigational information because presentation of wrong data is more critical than no data provided. Therefore a validation of the navigational data must be done which also means a transfer delay due to the validation time. Navigational information can be received from many sources, such as onboard systems, hydrographical and meteorological providers, or from the traffic stations that provides fairway information to be used for navigational purposes.

Based on the experiences from the MarCom scenarios we can see that the navigators in some settings have too much information and must therefore be able to filter it such that only significant information is displayed. Sea transport is global and the providers of data are dissimilar, depending on the position of the ship. This requires international standards to provide data in a unified format to minimize the risk of confusions and avoid misunderstandings.

[iv] http://www.olf.no/aktuelt/muligheter-for-300-milliarder-kroner-i-oekt-verdiskapning-article1732-223.html

2.8 *IMO e-Navigation objectives: 'Integrate and present information onboard and ashore to manage the workload of the users, while also motivating and engaging the user and supporting decision-making'*

The above issue has been focused in the Integrated Operation case study, and will become a part of one of the MarCom pilots. The idea is to share the same information between the operational planning centre, the vessels involved, the offshore installations, and eventually the system equipment providers. The objective is to convey the information as close to the decision makers as possible, in real time, which will result in an easier decision line between those involved in the execution of a decision and those planning the operation. By having better means to monitor the equipment status and condition, it will be possible to avoid unexpected situations with a real-time status of the equipment.

MarCom studies have shown that there might be several different communication channels used in an operation. Needs for a solutions such as an intelligent router that can be used to select proper channels to transfer data based on availability are obvious. Another observation is that the presentation of the information should be done in a standardised way to avoid misunderstanding between the users. If all workers being physically involved in an operation also are involved when the decisions are made it seems most likely that correct decisions are reached upon.

2.9 *IMO e-Navigation objectives: 'Incorporate training and familiarization requirements for the users throughout the development and implementation process'*

This issue is very important regarding a successful implementation of a system. The desired situation when introducing a new system is that the users have a good understanding on the possibilities of the system, as well as having a feeling that the system is beneficial for them. This will again result in a more familiarization to the system and the user threshold will be lower.

Another observation is that the majority of maritime workers is getting older and will retire in a few years time. A new generation sailors are about to enter the sector, and with them also requirements on higher bandwidth, since they are used to be surfing the Internet and being more integrated in the society ashore. One challenge in the change of working generations is to preserve the knowledge from one generation to another. This can be done by training and courses offered to the new generation, but another viable solution is to establish an operational centre that both can monitor equipment etc. along being utilized to give expert advices about the ship and its condition. In order to manage such a system an online ship-shore communication channel providing satisfactory capacity to transfer data being used in a decision process is required.

Training applications and video conferences need high data rates, likely more than 2 Mbps. In MarCom we have particularly studied the emerging WiMAX technologies that provide enough bandwidth to support transfer of video and pictures between ship and shore sites. Technologies that only provide low capacity channels supporting but transfer of small data packages are not suitable for this purpose.

2.10 *IMO e-Navigation objectives: 'Facilitate global coverage, consistent standards and arrangements, and mutual compatibility and interoperability of equipment, systems, symbology and operational procedures, so as to avoid potential conflicts between users; and be scalable, to facilitate use by all potential maritime users'*

Use of standards and routines with a global perspective is important in the maritime industry, since many of the users are sailing long distances and crossing many borders with different jurisdictional responsible communities. Critical systems used for navigational purposes should therefore be developed to enable operations on a global level and preferably be presented in a common way independent of the data providers. It is also beneficial to have common operational procedures to avoid conflicts and misunderstandings, especially in a critical situation.

Regarding deployment of communication systems there are different aspects that do not make all of them possible to be used on a global basis. The development of new maritime communication technologies is presently not market-driven because of the initial number of users being limited. Deploying wireless systems with high bandwidth to cover a wide area is also quite expensive, and must be performed not only to reach everyone everywhere, but also from needs to support safe operations in harsh environments. The approach must thus rather be to state that there is a requirement for access to communications, and that suitable systems must be implemented. Based on experience when the systems are available the traffic will grow, like when the Inmarsat system was implemented the most important consideration was "Safety of Life at Sea" and IMO was an active participant in the establishment. Later it appeared that the Inmarsat system became a gold mine for equipment manufacturers, system operators and the service providers, and it became an indispensable service for the users.

3 CHALLENGES AND POSSIBLE SOLUTIONS

The challenges in MarCom have been to identify user requirements to both applications and technology. The development of new maritime communication technologies is presently not market-driven because of the initial number of users being limited. The maritime sector has a relatively low number of users, and thus not sufficiently attractive to commercial actors.

The focus could rather be on some sectors having the capability to finance deployments of a communicational infrastructure. Another observation is that the maritime sector is of global nature, and it is not easy to harmonize licensing of available communication frequencies, since there are many commercial interests involved. Each country has the authority to manage their frequency resources, and the harmonization between countries is not satisfactory regarding frequencies for maritime use. Solutions like 'intelligent toolboxes'/'smart routers' and reconfigurable radio's to switch between channels based on availability and bandwidth requirements are therefore of high importance to maritime users operating globally. At the same time safety critical applications must be provided with dedicated radio channels being globally applicable and capable of supporting applications with high integrity and availability requirements.

Another challenge strongly connected to the requirements regarding a globally harmonized solution is the poor developed communication infrastructure at high latitudes, i.e. beyond about 70°N. The maritime traffic is expected to increase significantly in these areas in a few years time due to the ice meltdown in the Arctic waters. Possible solutions to this challenge are investigated in the MarSafe project[v].

One objective in the MarCom project is to enable provision of high bandwidth to specific areas, and the Mesh networking methods being investigated are attractive to maritime users in areas where a new network can be deployed to accommodate those needing bandwidth for special operations. By establishing such ad-hoc networks the coverage area is extended, since the signal can be transferred by using each other as relay units in a network with multi-hop capabilities. This is beneficial in parts of North Sea and the Norwegian Sea, where e.g. offshore oil installations have fiber connections, and may therefore be used to accommodate base stations in a mesh network. Preliminary investigations have indicated possible coverage ranging to about 20 nm (∼37 km) from an off shore WiMAX base station operating at 2.3 GHz, a rather encouraging result.

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7.2
Some radiocommunication aspects of e-Navigation

K. Korcz
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: In the paper some radiocommunication issues concerning Global Maritime Distress and Safety System (GMDSS) in respect of the e-Navigation have been described. Some aspects of the existing technical and regulation constraints and limitations referring to GMDSS equipment and systems have been given. The issues relating to the need of GMDSS modernization taking into account new technology and the discussion on the e-Navigation program have been presented.

1 INTRODUCTION

The MSC (Maritime Safety Committee) at its eighty-first session agreed to add a high priority item on the Development of an e-Navigation strategy to the work programme of Safety of Navigation (NAV) and Radiocommunications, Search and Rescue (COMSAR) Sub-Committees. As outlined in the document MSC 81/23/10 which proposes the development of an e-Navigation strategy, it is envisaged that a data communication network will be one of the most important parts of the e-Navigation strategy plan. In order to realize efficient and effective process of data communication for e-Navigation system, existing GMDSS equipment, as well as new radio communication systems could be utilized.

Ten years have passed since the time when the Global Maritime Distress and Safety System (GMDSS) became introduced. Planning for the GMDSS started more than 25 years ago, whereas its elements have been in place for many years.

There have been numerous advances in the use of telecommunications to further maritime safety, security and environmental protection during these periods. Although Inmarsat has provided significant advances for the collection and dissemination of Maritime Safety Information (MSI), distress alert reception and follow-on Search And Rescue (SAR) coordination communications, and the changes and upgrades, such as paperless NAVTEX receivers have been made, there is no systematic, planned programme to ensure the GMDSS remains modern and fully responsive to the needs of maritime safety and security.

On the other hand there are some obsolete GMDSS equipment and systems which had saldom or never been used in practice. For example NBDP had never been used for distress and safety purposes. After the activation of a distress alert on MF/HF DSC, the distress and safety communication is established on a MF/HF radiotelephony frequency only.

Not only in the Author’s opinion, the time is ripe to start the wide discussion on the real condition of the marine radiocommunication, with reference to the current discussion on the e-Navigation strategy. In the paper the discussion course at COMSAR Sub-Committee meetings has been taken into account as well.

2 GMDSS AND THE E-NAVIGATION PROGRAMME

For e-Navigation purposes, the COMSAR Sub-Committee considered the implications of developing a common information data source, delivering resilient communications, data provision and integrity, based on the requirements and the general conclusions from the preliminary user needs analysis.

In the consideration the following high level user needs have been addressed as a minimum:

- Common Maritime Information Data Structure;
- Automated and Standardized Reporting Functions;
- Human Centred Presentation Needs;
- Effective and Robust Ship and Shore communications;
- Human Machine Interface;
- Data and System Integrity;
- Analysis.

During the discussion at the COMSAR Sub-Committee meetings it was agreed that the needs of seafarers were central in the development of the e-Navigation strategy. However, authorities also had valid security, environmental, and search and rescue responsibilities. Ship and shore needs needed to be treated as a whole. Further e-Navigation can be used as a way to increase shore control over shipping. This should not be implied in the consideration of the needs of the shore component. The need for ships to keep appropriate autonomous control was to be maintained.

Although it was appropriate to start work on the technical aspects of communications supporting e-Navigation now, the e-Navigation strategy was still not complete, so this work had to be considered as preliminary and would have to be revised at a later date. However before further consideration some basic assumptions should be made:

– it should concern data communications; voice communications would also form a part of e-Navigation, but the present emphasis was primarily on data transfer;
– there would be different requirements for data availability depending upon the nature of the information being transmitted; for instance, information that was time and safety critical needed to be transmitted and received by the affected users quickly and reliably, whilst less time critical information would have a lower priority;
– the ship would receive a lot of information and it was important for the crew to be able to manage these data effectively;
– e-Navigation should not be seen as limited to safety and security at sea and protection of the marine environment functions only, as efficiency was an important potential benefit for ships and their crews; and
– data communications via satellite, as well as over terrestrial links, e.g., Medium Frequency (MF), High Frequency (HF), and Very High Frequency (VHF) would be used.

In general a ship in port could receive e-Navigation information through a wire. For wireless systems the expansion of bandwidth needs in the future should be expected. Therefore a wide variety of communications links could be foreseen, and it was too early to exclude any possibility.

Based on the findings of the Correspondence Group on e-Navigation strategy, including the above mentioned assumptions and discussion during the COMSAR Sub-Committee meetings the following recommendations and guidance could be given.

2.1 *Existing international regulations and standards relevant to the high level communications*

With respect to existing international regulations and standards relevant to the high level communications, it can be agreed that the user needs, as identified in SOLAS regulation IV/4, were the following data functions (also see Table 1) (IMO. 2004):

1 transmitting ship-to-shore distress alerts;
2 receiving shore-to-ship distress alerts;
3 transmitting and receiving ship-to-ship distress alerts;
4 transmitting and receiving search and rescue coordinating communications;
5 transmitting and receiving on-scene communications;

Table 1. Existing user needs relating to SOLAS Reg. IV/4.

User needs SOLAS IV/4	1)	2)	3)	4)	5)	6)	7)	8)	9)
VHF-DSC	x	x	x	x	x			x	x
SART						x			
NAVTEX							x		
EGC							x		
EPIRB	x					x			
MF/DSC	x	x	x	x	x		x	x	x
Inmarsat SES	x	x	x	x	x		x	x	
HF/DSC	x	x	x	x				x	x
Two-way VHF					x			x	x

6 transmitting and receiving signals for locating;
7 transmitting and receiving maritime safety information;
8 transmitting and receiving general radiocommunications to and from shore-based radio systems or networks; and
9 transmitting and receiving bridge-to-bridge communications.

While the COMSAR Sub-Committee meetings also noted that the user needs other than the GMDSS functional requirements and related equipment did not fall within its remit, however, it decided to additionally consider Automated Identification System (AIS), Long-Range Identification and Tracking System (LRIT) and Ship Security Alert System (SSAS) equipment, as specified in SOLAS regulations V/19, V/19-1 and XI-2/6 respectively. Additional user needs might be included at a later occasion as the development of e-Navigation was an ongoing process.

2.2 *Existing international regulations and standards identified which would need to be addressed, or further developed, to provide a harmonized resilient system*

There are about 130 performance standards and test standards related to GMDSS equipment mandatory or not mandatory according to SOLAS. As of today, taking into account present development of the marine electronics systems, about 10 of them should be modified or suppressed and about 40 should be definitely suppressed as obsolete. But it is difficult to identify in details which existing regulations and standards would need to be further developed or revised because the e-Navigation system was still at an early stage of development.

2.3 *Existing technical constraints and limitations, in terms of bandwidth, frequency and power consumption*

E-navigation should not be limited to communications using existing equipment, but the first phase should be to make better use of existing technology. Other technologies could come later. It had to be recognized that there were limitations on spectrum availability and that other types of technology might have to be used. It might also be necessary to pay for data communications. It is also recognized that the current systems were not adequate for expected types of high rate data (for example Inmarsat C had a data rate of 600 bps). There are no mandated requirement for a higher data rate but other satellite systems are available and can possibly be used for transfer of e-Navigation data.

2.4 *How should communications and information systems be developed and coordinated internationally and within technical standards for data structure, technology, bandwidth and frequency allocations?*

There is a need to have a common data structure and management so that the information would be available on board and could be used by different systems without the need to have to continually re-enter data. This would reduce the administrative load on ship crew as various reporting requirements could be extracted through filters automatically.

2.5 *Potential regulatory and technical problems that will need to be overcome considering that e-Navigation is to be scaleable across small and large vessels alike*

The question of e-Navigation being scaleable across small and large vessels alike is of relevance when small vessels and SOLAS ships needed to access e-Navigation data. National maritime administrations would need to include smaller vessels in the e-Navigation system. However, small vessels might have other means in addition to mandatory communications equipment such as VHF, of obtaining e-Navigation information such as mobile phones. Smaller vessels might also have power limitations and smaller presentation displays. In addition, the level of training might not be of the same standard as for SOLAS ships.

2.6 *Measures to reduce the number of false distress alerts*

The consequences need to be borne in mind. In order to reduce the occurrence of false distress alerts a unified written operating procedure and method in initiating distress alert had to be in place, a unified high rate of false alerts could be due to crew not being familiar with the operation of DSC devices, not following IMO guidelines and procedures or usage issues, i.e. the question of human machine interface problems.

The false alerts were occurring only in the GMDSS system and were an unintended consequence. The e-Navigation concept was still being developed but the possibility of similar unintended set of specifications for distress alert buttons should be provided to avoid confusion among users and a unified, effective and safe test function should be provided on the equipment.

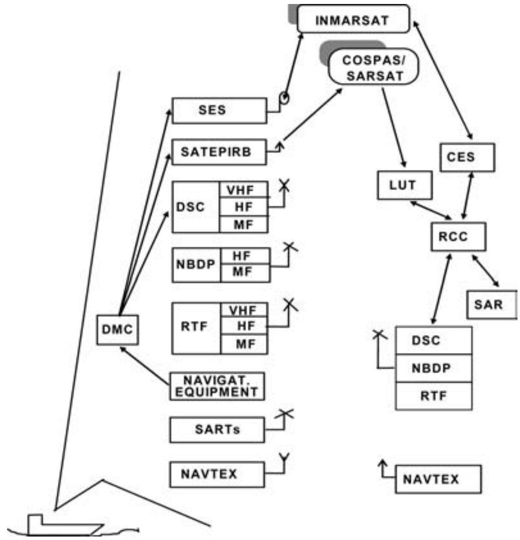

Figure 1. Equipment and systems of GMDSS (Korcz K. 2005).

The false alert problem touches on almost every subject of concern to the COMSAR Sub-Committee, including GMDSS, and Search and Rescue procedures. Because of the early and preliminary nature of the e-Navigation strategy development, there is no way to find a solution at this time from an e-Navigation perspective. However, it demonstrates the importance of standardization, clear procedures and effective training (MSC/Circ.1091) in the development of e-Navigation.

3 NEED OF GMDSS MODIFICATION

In 1988, the Conference of Contracting Governments to the 1974 SOLAS Convention on the Global Maritime Distress and Safety System (GMDSS) adopted amendments to the 1974 SOLAS Convention concerning radiocommunications for the GMDSS. These amendments entered into force on 1 February 1992. On 1 February 1999 the GMDSS became introduced for all SOLAS ships.

The following radio equipment and systems are provided for the GMDSS (Figure 1):

- Digital Selective Calling (DSC);
- INMARSAT Satellite System;
- SATellite Emergency Position Indicating Radio-Beacon (SATEPIRB);
- Search And Rescue Transponders (SARTs);
- NAVTEX System;
- Narrow Band Direct Printing (NBDP);
- Radiotelephony (RTF);
- Distress Message Control (DMC);
- navigational equipment (for support).
- Other elements of GMDSS to be showed in Figure 1 mean as follows:
- INMARSAT Coast Earth Stadion (CES);

– INMARSAT Ship Earth Station (SES);
– COSPAS/SARSAT Local User Terminal (LUT);
– Rescue Coordination Centre (RCC).

Communications will be essential to e-Navigation, in particular for collecting and integrating sources of navigation information and providing the user with the optimum, relevant data on a multi-function display. The modes of communication covered by the concept are following:

– intra-vessel;
– ship-to-ship;
– ship-to-shore and shore-to-ship;
– shore-to-shore.

A systematic and continuing review is needed to ensure the GMDSS remains responsive. Below some categories suggested for review have been given.

3.1 *Functional requirements*

The GMDSS was built upon satisfaction of functional requirements (SOLAS Chapter 4, Reg. 4) mentioned above. Any review of the GMDSS should start with an examination of the functional requirements. At the beginning of these consideration the answers to the two following questions should be given: are deletions of any requirement possible? and do others need to be added?

Consideration of these questions allows to come to the conclusion that no functions were candidates for deletion, but at least two or more may need to be added – for example interoperability with non-SOLAS vessels and communications with commercial aircraft. Also, there may be a need for high data rate systems in some vessels for use during mass evacuation incidents.

3.2 *Carriage requirements and areas of operation*

Four areas were defined where carriage requirements differ. It should be considered if this concept is still relevant, taking into account large variety of the ship types and the sea routes.

3.3 *Advances in technology*

Much of the GMDSS equipment is built on technologies more than 20 years old. Some of them work well and others do not. Further, many new and less expensive technologies have emerged including:

– radio systems with embedded position information;
– Low Earth Orbit (LEO) satellite systems with hand held terminals; some provide excellent coverage in Polar Regions; the Polar Regions are growing in importance (new NAV/MET Areas have been defined to cover these areas);
– regional satellite systems have been implemented with attractive features;
– web-based access to non-alert MSI; further data rates supported by NAVTEX and SafetyNET may not be sufficient; the relationships between the historical "push" of information and new technologies that allow "pulling" it may need attention;
– inexpensive hand-held radios – for example, small cheap VHF-AM radios could be placed in some survival craft for communications with commercial aircraft; and
– cellular phones.

3.4 *Related systems and initiatives have been or will be put in place*

At present above includes:

– Automatic Identification Systems (AIS);
– Ship Security Alert Systems (SSAS);
– Long-Range Identification and Tracking (LRIT);
– commercial HF service systems that are not part of the GMDSS, but they serve thousands of ships. These include HF e-mail, which is used widely, but it is not part of the GMDSS;
– e-Navigation programmes.

3.5 *In some cases implementation has not proceeded as planned*

Among other things it applies to:

– many HF/MF and VHF commercial stations have closed, and commercial use of DSC and NBDP has diminished;
– implementations of areas A1 and A2 have been slower than anticipated; and
– DSC is still not as widely used as expected.

4 CONCLUSIONS

One of the three main elements of e-Navigation is Communications. Taking into account the earlier consideration, doubtlessly the communications media for e-Navitation should include both terrestrial and satellite communications.

There is increasing demand for a common communication platform for two-way data communication between ship and shore. There is also a growing requirement for Internet access on ships, at sea as well as in ports.

There are many data communications technologies that are likely to play a role in e-Navigation. In addition to fixed communications, the mobile communications technologies that could be used include but are not necessarily limited to radio (HF, VHF or UHF – Ultra High Frequency), AIS, WiFI and WiMax, satellite communications including Internet Protocol (IP) broadband. Communications can be either point-to-point or broadcast and could be based on IP but not necessarily on the Internet itself.

The selection of the particular technologies used to provide services must be made carefully and should depend on the specific task to be undertaken.

So, the GMDSS equipment can be an effective way to increase the reliability of e-Navigation data communication network but must be improved. This goal can be achieved as the result of the work on two items (Korcz K. 2007):

- technical improvement of GMDSS; and
- utilization of technically improved GMDSS equipment for e-Navigation.

In addition, it is necessary to ensure that man-machine-interface and the human element will be taken into account including the training of personnel. The lessons learnt from the development and operation of GMDSS and AIS should be taken into account in the development of e-Navigation as well.

Taking into account the above mentioned a systematic process is needed for continuous review of the GMDSS to ensure it remains modern and fully responsive to changes in requirements and evolutions of technology and it will meet the e-Navigation programme requirements.

For assuming this process a mechanism for continuous evolution of the GMDSS in a systematic way should be created. Some evolutions are within the sole purview of the IMO (in particular COMSAR Sub-Committee) while others will require co-operation from others such as the ITU/ICAO, etc. The COMSAR Sub-Committee is competent to initially discuss these issues in part under several agenda items. These agenda items include:

- GMDSS;
- Developments in maritime radiocommunications systems and technology;
- Development of an e-Navigation strategy; and
- Development of procedures for updating shipborne navigation and communication equipment.

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7.3 On-board communication challenges (LAN, SOA and wireless communication)

L. Mu
University of Agder

N. Garmann-Johnsen
Origo Mobikom AS, Kristiansand, Norway

ABSTRACT: The main objectives of the MarCom project (Maritime Communication, broadband at sea) are to investigate the main user needs and requirements to communication technologies within the maritime community. An important part of this is providing on board services to the crew, passengers and ship operations. In order to facilitate this the MarCom project will propose a Generic Scalable Service Platform to handle the 'nuts-and-bolts' of communication.

In this paper we will indicate what challenges and possibilities this implicates for a solution for On-Board LAN (**L**ocal **A**rea **N**etwork), SOA (**S**ervice-**O**riented **A**rchitecture), and wireless communication.

1 INTRODUCTION

The main challenge in the (whole MarCom-project) will be to find out how to adapt existing and emerging land based communication technology to the limitations that maritime use entails: Enormous areas to cover, poor or no infrastructure on land, low density of users and limited willingness to pay for services/small volumes of demand today.

The solution lies in integrating the different technologies, develop solutions for multi hop and ad hoc networks between stable and mobile units, and an ICT architecture (software and network) that allows for variation in service quality.

In addition one must stimulate increased use of communication services on board in order to get a broader base for payment.

This will be done through the development for several new applications for use on board.

We will exploit the synergy between low cost wireless communication ship to shore and ship to installation at sea (oil platforms etc) on one hand, and WLAN on board on the other hand.

Accordingly we have launched the following three R&D priority fields as the most important in the project: (themes of this paper in bold)

- Communication ship to shore
- **A generic scalable ICT service platform**
- **Optimized maritime mobile and wireless LAN-solutions**

2 MARKET PULL AND TECHNOLOGY PUSH

User requirements and needs are there which we will take a look at them in this paper, and there are technologies we already have and some we do have to develop. All those pull or push us when working with the MarCom project.

2.1 *Application groups*

Analysis of the cases in MarCom Project Work Package 3 (WP 3) resulted in finding six common application groups as shown in the figure below[1]:

2.1.1 *Technical maintenance*

These applications deal with reporting condition of the ship or platform, and (remotely) updating data and software. This group of applications includes:

- State monitoring and analysis: This is technical monitoring system, detection tools, information system, remote control system for monitoring of oil, gas, water tanks and sewerage system. This updates of FDV systems
- Online SW updates and maintenance, such as new SW versions on applications monitoring e.g. the propulsion machinery
- Online data updates, such as online updates of ENC's (both for ECDIS/other chart systems onboard and for pilot laptops), online updates of meteorological

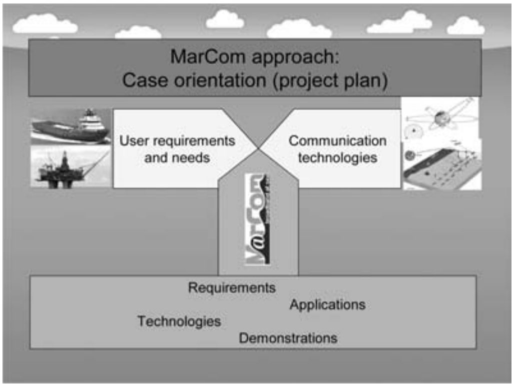

Figure 1. MarCom is the result of user requirements and communication technologies.

1	Technique Maintenance
2	Reporting
3	Safety & Monitoring
4	Training & Qualification
5	Infotainment
6	Special Purpose Applications

Figure 2. Common application groups.

and hydrological data, technical drawings, sea maps/3D seabed topology, updates of documents and regulations following a vessel

2.1.2 *Reporting*
These applications are related to the (onshore) management's need for tracking and status reports from their ships. This can include operational and technical information about the ship and its cargo, but also navigational reports and data needed by government regulations fit within this group.

2.1.3 *Safety and monitoring*
These applications deal with automatic monitoring of equipment and overall state, for instance surveillance. The events to monitor are not only equipment failure and accidents, but also terrorism and environmental threats.

2.1.4 *Training and qualification*
The 'Training and qualification' application group consists of applications concerning the knowledge and expertise of the crew onboard vessels. Examples of applications are:

– Inspection for qualification of crew (e.g. sobriety tests)
– Certification of crew
– Enhance the knowledge of the crew
– Courses and training
– Updating certificates

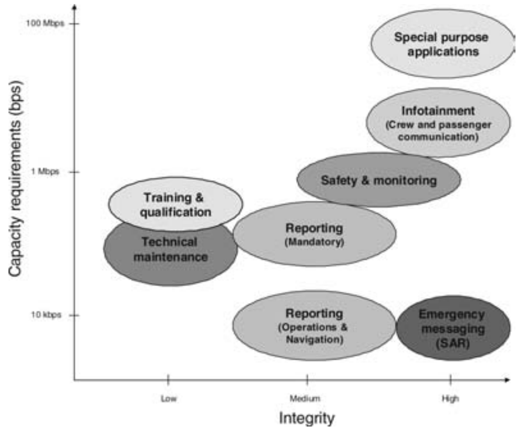

Figure 3. Today's capacity and integrity requirements for MarCom application groups.

2.1.5 *Infotainment*
Infotainment is an expression used for information and entertainment applications. This includes services to the crew and passenger such as:

– TV and movies
– Internet access to passengers
– E-mail and internet for crew
– Video conferences
– Remote ticketing
– Remote monitoring of transactions (cash register)

Information to passengers (map, position, advertisements, traffic information)

2.1.6 *Special purpose applications*
This group contains special applications that are unique for a single or small group of companies. These applications usually have high demands on both capacity and integrity. In the MarCom project we will deal with special purpose applications within the Oil and Gas IO. Examples on such applications are real-time updates of information between all nodes in the IO infrastructure and real-time monitoring of complex offshore operations.

2.2 *Requirements for those applications*

2.2.1 *Bandwidth and quality of service*
The bandwidth and integrity (quality of service and uplink time) requirements are summarised in the following figure.

2.2.2 *Security requirements*
The security requirements on the communication channel differ from application to application. The main threats on the communication channel level are denial of service and traffic analysis attacks. Hence, protection of important user data can be implemented on higher layers (the network, transport or application layer).

Seen from a user point of view, a division in low, medium and high security requirements have been provided for each group of applications.

Low means that losing some of the data to unauthorised persons is not crucial.

Medium means that losing some of the data to unauthorised persons is not desirable, but still not crucial.

High means that losing data to unauthorised persons is crucial and one should stress to secure the communication channels.

2.2.3 *Protocols and message formats*

The messages and protocols used in the applications should be based on open standards as much as possible. The exact protocols and formats to be used have to be decided when more work is done in WP 4, 5 and 6. Some examples of possible standards are:

Protocols

- VHF data link (VDL) for transfer of Automatic Identification System (AIS) messages.
- Short Messaging Service (SMS) for transfer of small status messages via GSM.
- Internet Protocol (IP) for transfer of larger data packages such as large reports, documents, experimental data, images and pictures. This can be TCP/IP (point to point communication) or UDP/IP (broadcast).
- SMTP for transfer of e-mails

Messages

- National Marine Electronics Association (NMEA) message format for messages transferred on AIS network and for communication with navigational onboard equipment.
- XML format for reports and services to the crew/passengers (infotainment)
- JPEG, GIF, BMP, PDF, WMF for transfer of images and pictures
- E.g. AVI for transfer of live video from web cameras

2.3 *MarCom communication technologies*

2.3.1 *The ICT-solutions*

Hardware-configurations [2]:

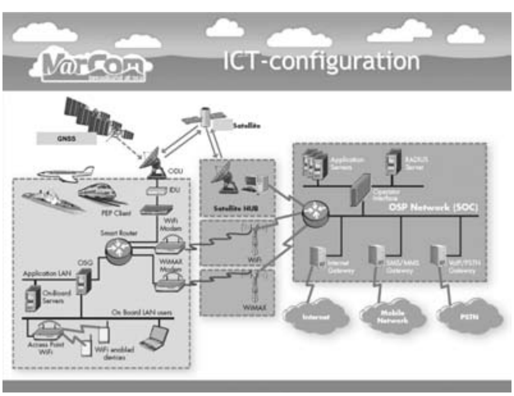

Figure 4. MarCom R&D arena framework.

Focus-areas [3]:

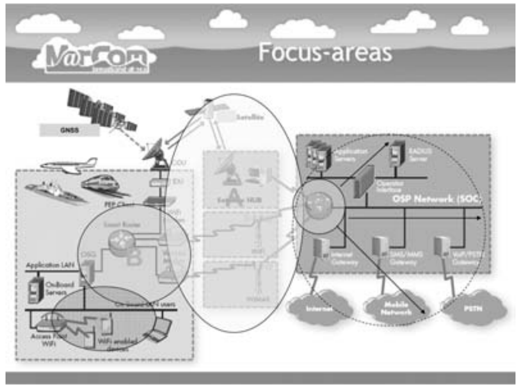

Figure 5. R&D focus areas.

A: Communication Vessel⇔Land

B: Generic scalable ICT service platform – supplied by a smart router

C: Optimized maritime mobile and wireless LAN

During work in the project, we, Work Package 5 (WP 5) will focus on B and C and OSP Network in the figure above. We will also expand the software engineering focus to include the basis for land based networks to work in conjunction with the ones on board.

2.3.2 *Generic on-board architecture*

Figure6 is about the generic on-board architecture, and figure7 is the CALM station reference architecture.

Communications, Air-interface, Long and Medium range (CALM) is an initiative by the ISO TC 204/Working Group 16 to define a set of wireless communication protocols and air interfaces for a variety of communication scenarios spanning multiple modes of communications and multiple methods of transmissions in Intelligent Transportation System (ITS)[4].

2.3.3 *Service-oriented architecture*

In computing, Service-oriented architecture (SOA) provides methods for systems development and integration where systems group functionality around

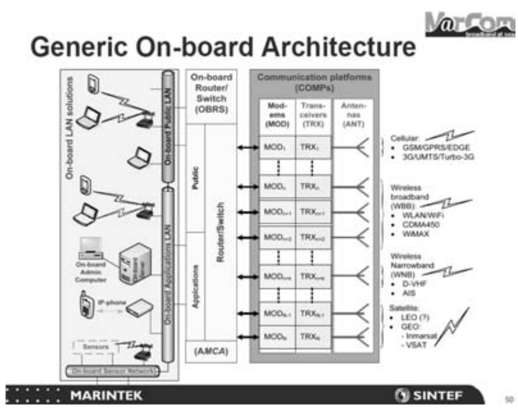

Figure 6. Generic on-board architecture.

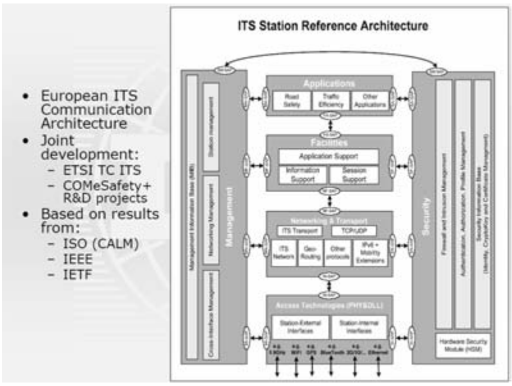

Figure 7. ITS station reference architecture.

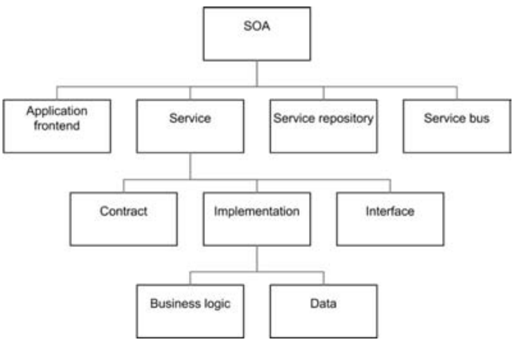

Figure 8. Elements of SOA[6].

business processes and package these as interoperable services. SOA also describes IT infrastructure which allows different applications to exchange data with one another as they participate in business processes. Service-orientation aims at a loose coupling of services with operating systems, programming languages and other technologies which underlie applications. SOA separates functions into distinct units, or services, which developers make accessible over a network in order that users can combine and reuse them in the production of business applications. These services communicate with each other by passing data from one service to another, or by coordinating an activity between two or more services[5].

3 CHALLENGES AND APPROACH

3.1 *Challenges*

As we figured out before: there is a great need for broadband at sea, applications on-board have different capacity, integrity requirements and the security requirements, and they want the flow formats and protocols are based on open standards as much as possible. We detail those challenges below:

- Network solutions satisfying the vessels needs for local infrastructure and services (WiFi/WLAN, WiMAX, GSM+, 3G)

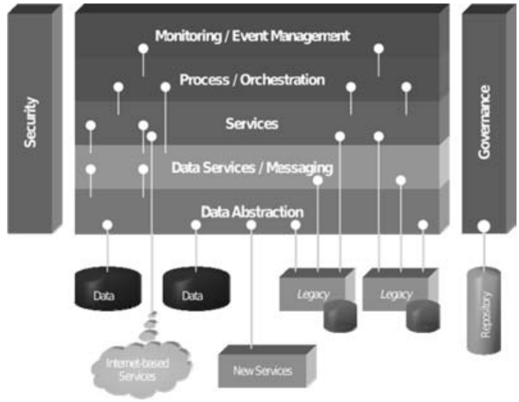

Figure 9. SOA meta model[7]

- Advanced middleware enabling a.o. (IP-based)
  - Interactive multimedia communications (IP-phone, Internet…)
  - Sensor networks implementation
  - Seamless and continuous handover and roaming
- An architecture reflecting different security levels:
  - Intranet for internal communications
  - Extranet for cargo control etc.
  - Sensor networks for data collection, handling and control

One also has to think of:

- Research and innovation; how and where to push state-of-the-art ahead (MarCom is a usability study with intermodal/ maritime transport and supply systems, so it is not necessarily within ICT one wishes to push the state of the art further ahead, rather the use of it.)

3.2 *Approach*

The purpose of this part of the MarCom-project is to demonstrate the benefit of broadband at sea, and land-to-ship ICT-integration through the development of a demonstrator for "The generic scalable service platform" (Integrated platform, GSS). The main requirements for this platform are to provide an integration platform for:

- Several on-board applications
- Integration with systems and utilities onshore (cloud computing, Software as a Service (SaaS)...)
- Provide seamless roaming of data communication between different communication technologies and infrastructures (Wimax and likes of it-, 3G/ 4G mobility, VHF/ UHF, NMT, SatCom etc.) and Multihop networks
- WLAN and data capture/sensor networks
- Cope with different communication service levels (SL's)
- Sort and prioritize communication with different SL's

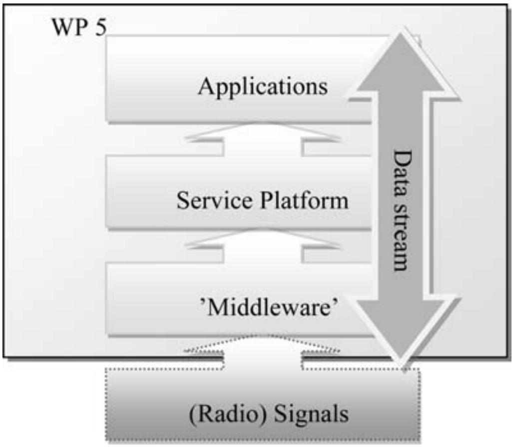

Figure 10. Overview of the MarCom software development[8].

The solution must (on a commercial basis) accommodate shared applications/cooperation technologies; GIS/planning systems etc. from any 3rd party application or content provider, for use in integrated operations and commercial shipping in general.

The service platform will be developed on SOA architecture, and the cloud computing and SaaS technologies could be used. Then the applications on-board could take advantage of those technologies too.

To deploy an optimized maritime mobile and wireless LAN on board, one main theory is to build on the CALM-standard; and build a dialect of this (CALM-SEA). This can be a topic for a new European R&D project (EuroMarCom), to finance further work.

3.3 *Service platform*

One of the greatest challenges is of course getting the signal to the ship with high enough bandwidth and integrity. This is the main focus of the MarCom project and is described in another TransNav paper. Another major challenge is how to make use of the signal, maintaining the needs of all the partners (crew, captain, ship owner, government etc) involved. To ascertain this, there is a need to develop a common platform that handles the nuts-and-bolts of the communication.

This service platform can be described as having three layers. First, the Middleware receives the signals and makes it available to the recipients. The service platform performs common tasks, like usage tracking for billing, deciding bandwidth need for each request and performing authorization and validation. Finally, there are applications, as described before.

The figure below shows a high level overview of the software being developed in MarCom. Note that the data stream will go both ways.

3.3.1 *Signals*

These are the signals received on board and transmitted from the ship. How the signal transfer is done is the topic for other work packages in MarCom. The signals could also be from on-board entities such as sensors etc.

3.3.2 *Middleware*

The middleware receives different signals (GPRS, WiMax, UMTS, AIS etc) and makes the data stream available for the upper layers. This layer will also translate the data stream from the upper layers into appropriate and available formats for transport out of the ship.

3.3.3 *Service platform*

The service platform will provide services (API) to the applications for easy use of the broadband available. The functions provided by the service platform will typically be related to security, billing and notification services.

3.3.4 *Applications*

This layer represents the actual applications; e-mail, maintenance surveillance, video etc.

4 ABBREVIATIONS

Abbreviations (in order of appearance in paper)

ICT	Information and Communications Technology
WLAN	Wireless Local Area Network
R&D	Research and Development
FDV	Functional Dependency Violated
SW	Software
ENC	Electronic Navigation Chart
ECDIS	Electronic Chart Display Information System
3D	three-dimensional
IO	Integrated Operations (here: in the Oil and Gas offshore industry)
VHF	Very high frequency
VDL	VHF data link
AIS	Automatic Identification System
GSM	Global System for Mobile Communications
IP	Internet Protocol
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
SMTP	Simple Mail Transfer Protocol
XML	Extensible Markup Language
JPEG	Joint Photographic Experts Group
GIF	Graphics Interchange Format
BMP	Bitmap
PDF	Portable Document Format
WMF	Windows Metafile
AVI	Audio Video Interleaved
OSP	Outside Plant (network)
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
3G	Third generation telecommunication
IP-phone	(VoIP) Voice over Internet Protocol
UHF	Ultra high frequency
NMT	Nordic Mobile Telephone

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

7.4 Towards standardized maritime language for communication at sea

B. Katarzyńska
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The paper deals with attempts of international community at standardizing the language used for communication at sea. Key terms include Seaspeak, Wavelengths, Anglosea project, International Standard Marine Vocabulary, Standard Marine Communication Phrases, MarEng project materials.

1 INTRODUCTION

For many years there have been numerous efforts undertaken to standardize the language used for communication at sea between ships in different situations, between ships and VTS shore stations or between ships and helicopters in case of rescue operations.

These efforts were considerably speeded up by various disasters at sea where the lack of effective communication was evident like in the case of the "Scandinavian Star" or the "Estonia" where commands for evacuation were given in different national languages, which took a long time and resulted in heavy loss of life.

The early attempts were made by prof. Peter Strevens from Wolfson College, Cambridge and Captain Fred Weeks from Plymouth Polytechnic who developed message markers and published "Seaspeak" and "Wavelengths". Both handbooks were introduced and used in nautical colleges and maritime universities in different parts of the world.

At the same time the Canadian Coast Guard College in Nova Scotia started work on the Anglosea project and soon three video tapes covering St. Lawrence Seaway, The English Channel and Ship Repair in La Spezia were produced. They helped not only in practical training of the students by providing examples of communication on board ship in different parts of the world but also in raising the awareness of the importance of clear and unambiguous communication for the safety of the vessel, her crew and her cargo.

Way back in 1973, the IMO Maritime Safety Committee, at its twenty-seventh session, agreed that where language difficulties arise a common language should be used for navigational purposes and that language should be English. As we could see from numerous examples of disasters at sea, it was not always the case in practice.

In consequence of the IMO Maritime Safety Committee's decision, the Standard Marine Navigational Vocabulary was developed. It was adopted in 1977 and after being used in nautical colleges and maritime universities it was revised and amended in 1985.

The amended version was widely used both in maritime education and training institutions ashore and on board ships.

But accidents and disasters at sea have still been happening so there was a need for a more comprehensive version of the Standard Marine Navigational Vocabulary to improve communication among multi-lingual crews on board different ships.

In 1992, the IMO Maritime Safety Committee, at its sixtieth session, instructed the Sub-committee on Safety of Navigation to work on a more comprehensive standardized safety language than the SMNV 1985, taking into consideration the changing conditions of modern seafaring and covering all major forms of safety-related verbal communication.

In 1997, the IMO Maritime Safety Committee, at its sixty-eighth session adopted the Draft IMO Standard Marine Communication Phrases (SMCP) developed by the Sub-committee on Safety of Navigation.

Following the trial period at various maritime and training institutions, the Draft IMO Standard Marine Communication Phrases was amended at the forty-sixth session of that Sub-committee.

Many of the remarks were taken into account by the organization and the IMO Standard Marine Communication Phrases were given final consideration at its seventy-fourth session.

In November 2001 the IMO Standard Marine Communication phrases were adopted by the Assembly as resolution A.918/22

Under the international convention on Standards of Training, Certification and Watch-keeping for Seafarers, 1978, as revised 1995, the ability to use and understand the IMO SMCP is required for the certification of officers in charge of the navigational watch on board ships of 500 gross tonnage and more.

This requirement sparked off the development of various teaching materials in many parts of the world. Among them is the multi-media project called

MarEng, which is one of the EU projects in the Leonardo da Vinci programme.

It is a multi-media teaching and learning tool aimed at improving the knowledge of Maritime English of not only distance learners on board ships but also both the students and the teachers at nautical colleges and maritime universities all over the world.

Gdynia Maritime University in Poland is one of the material-making partners to the MarEng project. The other partners include:

– University of Antwerp, Institute of Transport and Maritime Management in Belgium
– University of Antwerp, Department of Business Communication in Belgium
– University of La Laguna, School of Nautical and Sea-related Studies, English and German Linguistic Studies, Santa Cruz de Tenerife, Spain
– University of Helsinki, Department of Translation Studies in Finland
– Aland Polytechnic, The Aland Maritime Institute in Mariehamn, Finland
– Sydvast Polytechnic, School of Maritime Studies in Turku, Finland
– Latvian Maritime Academy in Riga, Latvia
– University of Turku, Finland

Centre for Maritime Studies in Turku has been the co-ordinator of the MarEng project and the Lingonet company Oy in Turku has been responsible for the task of putting the material and the inter-active exercises into a multi-media format.

The MarEng project is an international project aiming at promoting the Maritime English competence of the people working in various maritime professions in different parts of the world so the intended users include those actually working at sea as well as those studying and working in a wide range of sea-related areas.

The MarEng project started in November 2004 and was completed in May 2007. Its final product is a web-based Maritime English learning tool in the form of an organised database of various Maritime English teaching and learning materials and a CD-rom.

The MarEng materials can be used online in the college classroom, in distance learning and for self-study purposes. There are a number of recorded texts and exercises of different types which the students are encouraged to do. Some parts of the MarEng materials are also available in the PDF format. The entire MarEng tool has been available on the Internet since April 2007, free of charge. It can also be downloaded from the website http://mareng.utu.fi

The MarEng materials produced so far are suitable for different language levels namely the intermediate level and advanced level.

Intermediate level materials cover the following sections:

1. In Port
2. Welcome to a Modern Port
3. Loading the MS Marina
4. The Ship and her crew
5. Leaving port
6. In the Fairway
7. Heavy Weather
8. Mayday Mayday
9. The crew and its tasks
10. At Sea – changing the watch
11. Survival in an emergency
12. Helicopter Rescue
13. An Encounter with the Coast Guard

The MarEng learning material in the intermediate section is based on the idea of a virtual ship on a voyage from the port of Santander in Spain to the port of Kotka in Finland, calling at a number of ports on the way. During the voyage, the crew of the mv "Marina" faces a number of routine situations as well as some unusual ones in which Maritime English is used both on board ship and in port loading and discharging operations.

Most of the texts have been recorded as well as numerous vocabulary and grammar exercises have been provided. There are clear instructions on how to use the programme and the students can listen to recordings as many times as they wish to do so.

There is also a section on maritime glossary with explanations in each of the sections.

Advanced level materials correspond to the topics covered in the intermediate level sections and include:

– Port Operations
– Shipping and Maritime Management
– Cargo Handling
– Vessel Types
– The Engine Room
– Cargo Space
– Port State Control
– Vessel Traffic Services (VTS)
– Ice Navigation
– Weather
– Radio Communication
– Radio Medical
– SMCP

The materials have been evaluated and tested by Advisory Partners including:

– APEC Antwerp/Flanders Port Training Centre in Belgium
– Finnish Ship Officers Union in Finland
– National Board of Education in Finland
– Latvian Maritime Administration in Riga, Latvia
– BORE Oy in Finland

Those interested in using the MarEng programme online are welcome to visit the webpage of the MarEng project at http://mareng.utu.fi or visit our computer laboratory where the MarEng programme has been downloaded on all the computers and see for themselves how the programme works and how can it be used in class.

Using the MarEng materials in practice will hopefully improve the knowledge of Maritime English among the multi-lingual crews resulting in better communication on board multi-national vessels, in more efficient port operations and safer navigation.

In conclusion, I would like to say that a follow-up to the MarEng project is now under way. It is called the MarEngPlus project and is going to cover the elementary level Maritime English materials.

The MarEngPlus project started on 1st October 2008 and will be completed by the end of 2010. It is also partly funded by the EU Leonardo da Vinci programme.

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7.5
Novel maritime communications technologies

F. Bekkadal
MARINTEK e-Maritime, Trondheim, Norway

ABSTRACT: Current maritime systems are to a large extent based on legacy analog VHF radios for ship-to-shore communications near port waters, and relatively low bandwidth digital satellite communications (SatCom) for long-range ship-to-ship and ship-to-shore communications. The cost of bandwidth for SatCom networks is expected to remain high due to the cost of launching satellites into orbit and also due to the stabi-lizers required for presently available on-board antennas. On the other hand, the legacy VHF system comprises low bandwidth radios incapable of supporting applications requiring high data rates. Unlike the terrestrial networks, advancement in maritime networks is severely lagging behind its land counterpart.

MARINTEK is the principle investigator of the *MarCom* project, a joint initiative between several national and international R&D institutions, Universities and Colleges, Public Authorities and Industry, funded by the industry itself and The Norwegian Research Council's MAROFF program, and aiming at developing a novel digital communication system platform to ensure the proliferation of innovative mobile network applications presently being widely implemented on land-based wireless systems.

1 INTRODUCTION

The infancy and youth of radio technology was primarily linked to maritime applications. Following his invention of the first operating radio transceiver in 1895, Guglielmo Marconi performed transmission experiments between two Italian warships outside the port of Spezia in 1897, where he managed to exchange radio messages at a distance of 22 km. Later he continued his experiments in England, where on Christmas Eve in 1898 he established radio telegraphy contact between the "East Goodwin" lightship and South Foreland Lighthouse in South East England. On 3rd March 1899 the steamship "R F Matthews" collided with this lightship, which alarmed the lighthouse ashore to obtain assistance. This was the first time ever a distress call was transmitted by radio from a ship at sea.

However, despite of the tremendous developments in radio technologies since that time, advancements in maritime networks are severely lagging behind its land counterpart, and novel solutions are needed to meet the imminent user requirements.

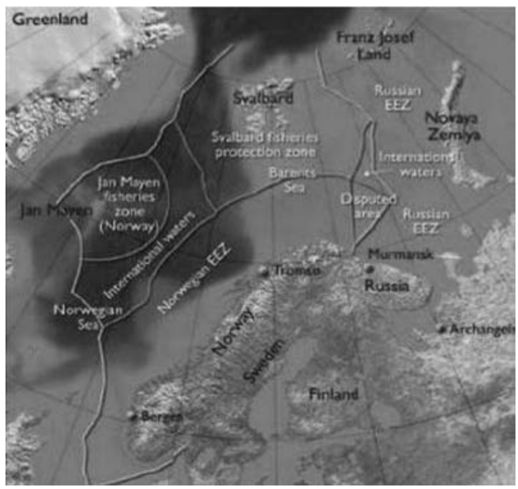


Figure 1. The 'Northern Challenges' exemplified by Norway's geography and economic activity at sea (Source: ACIA).

2 MARKET PULL VS. TECHNOLOGY PUSH

2.1 *The 'Northern Challenges'*

The overall backdrop of the maritime communications market pull is demonstrated by Figure 1, portraying the 'Northern Challenges', exemplified by Norway's geographical extension and economic dependability of an ocean area about 6 times the size of its mainland. The vast geographic distances and the economic importance of activities at sea in remote areas demand novel and innovative radio-based solutions. There are numerous unsolved research challenges regarding radio communications coverage throughout the vast region comprising e.g. the Norwegian Exclusive Economic Zone (EEZ) and the Arctic waters [1].

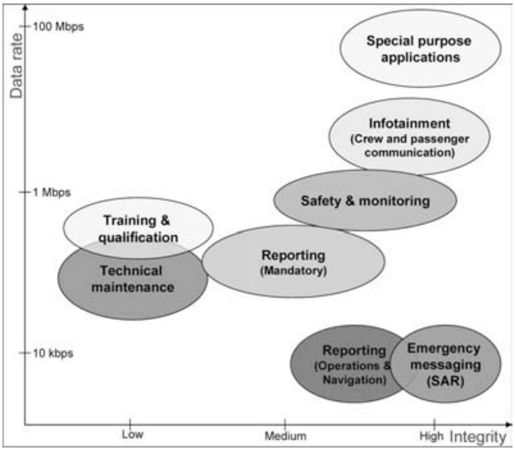


Figure 2. Speed vs. integrity diagram showing compiled user requirements in application groups [3].

2.2 *MarCom scenarios and strategic initiatives*

The specific market pull issues and user requirements pertaining to the MarCom project are investigated through the following 9 scenarios/user cases:

1 Monitoring of (domestic) ferries
2 Pilotage & maintenance of fairways, lighthouses and navigation marks
3 Integrated operations (IO's)
4 Passenger information on trains and at roads
5 High-speed craft (HSC) operations
6 Vessel-to-Vessel Relay and Mesh networking
7 Mobile on-board LAN-solutions
8 The High North challenges
9 International shipping

Furthermore the issue of novel maritime communication technologies will be an important aspect of the emerging e-Navigation and e-Maritime concepts – *e-Maritime* being proposed by the EU Commission (DG TREN) as an extension to the already developing *e-Navigation* concept originating from IALA and IMO strategic initiatives.

Bearing in mind that the ocean waters cover about 70% of the earth surface, that over 90% of the world's goods is transported by a merchant fleet comprising around 46.000 ships, and that there are about 4.000 viable merchant ports worldwide – literally thousands of ships are out of sight from land or any other vessel all the time – and thus making the global needs for reliable maritime communications paramount.

2.3 *Compiled user requirements versus available communication capacity*

The compiled user requirements derived from the scenarios referenced in paragraph 2.1 above, along with similar supplementary data from the EU-projects '*Flagship*' and '*EFFORTS*', have identified the application groups given in Figure 2 ([2], [3]).

Table 1. Presently available digital maritime communications.

System	Communication form	Data rate
NAVTEX	HF, MF	300 bps
DSC	VHF	1.2 kbps
GPS	Access via NMEA 0183	4.8 kbps
AIS	VHF	2×9.6 kpbs
EPIRB	Short messages (Satellite)	100 bits/hour
SSAS	Short messages (Satellite)	100 bits/day
SafetyNet	NAVTEX over Inmarsat	100 messages/day

Some ships have data links via Satellite (Inmarsat, VSAT...)

It is obvious that but a few lower classes of these application groups may be supported by the presently available digital maritime communication means depicted in Table 1, and thus novel maritime communication technologies have to be introduced to the maritime market.

3 NEW MARITIME COMMUNICATIONS

3.1 *MarCom major objectives*

MarCom's major technological objectives are to:

– Extend the coverage and range at sea for both in-use and novel terrestrial wireless systems/ technologies
– Find appropriate SatCom solutions to complement/supplement the terrestrial ones, mainly beyond their coverage
– Obtain seamless and continuous handover and roaming within and between the systems

3.1.1 *Terrestrial systems*

The appropriate terrestrial systems being applicable for maritime use may be categorized as follows:

1 Cellular systems
2 Wireless Broadband Access (WBA)
3 Wireless Narrowband Access (WNA)

The roadmap for *Cellular systems* evolution towards an alleged introduction of 'Next Generation Mobile Network' (NGMN) is illustrated in Figure 3, the main features being steadily increased capacity and versatility [4]. A significant milestone on this path is the 4G-3GPP LTE ('Long Term Evolution') advancement, expected to offer peak data rates of about 300 Mbps downlink and 80 Mbps uplink.

Actual *WBA systems* comprise mainly Wi-Fi/ WLAN and the emerging WiMAX technologies in accordance with the IEEE 802.11 and 802.16 standards, respectively.

For maritime users Wi-Fi is merely applicable for on-board purposes and close to shore (e.g. in harbors) due to its limited range.

However, WiMAX is considered a viable option for medium- to long-range broadband maritime communications, particularly if sub-GHz frequencies are applied – thus supposed to be capable of providing data rates >20 Mbps at ranges up to 50–100 km [5].

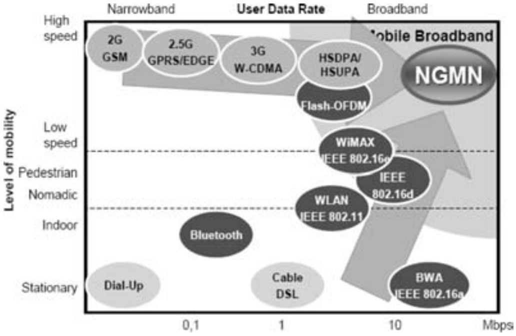
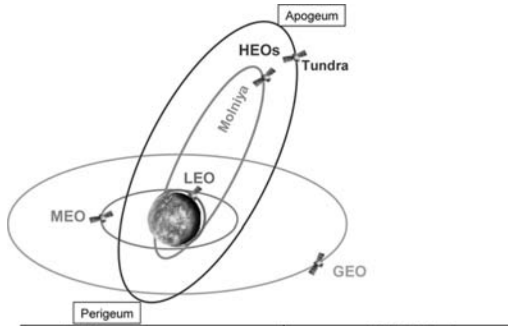


Figure 3. Wireless terrestrial systems evolution roadmap.



Orbit	Height [km]
LEO: Low Earth Orbit	200 – 2.000
MEO: Medium Earth Orbit	2.000-GEO; normally: 10.000-20.000
GEO: Geostationary Orbit	35.786
HEO: High Elliptical Orbit	500-50.000

Figure 4. Satellite orbits and their main features.

Relevant *WNA systems* are Digital VHF (D-VHF) and (partially) AIS, but the latter is presently offering only 2×9.6 kbps, and thus of no interest to the bandwidth-demanding services in Figure 2.

As the 1st generation of D-VHF systems Telenor Maritime Radio (TMR) devised a technology providing a.o. a 'broadband' service of 133 kbps by utilizing 9×25 kHz VHF channels, with a range of $\sim$130 km. TMR has deployed this system to cover all of the 2.400 km long Norwegian coastline, together with parts of the North Sea and the Norwegian Sea.

However, as a part of harmonizing the maritime D-VHF services a significantly more spectral-efficient solution has been introduced, indicating that the 2nd generation might increase the D-VHF's capacity by a factor of 3–10 [6].

3.1.2 *Future trends – terrestrial wireless systems convergence or coexistence?*

WiMAX is designed to deliver multiple types and levels of service through a flexible IP network architecture, authentication and Quality-of-Service (QoS) mechanisms. WiMAX can be implemented as a flat 'pure IP' network or as a part of a multimode service environment through application servers, network gateways and IP Multimedia Subsystem (IMS).

LTE is now heading in a similar direction in creating Orthogonal Frequency Division Multiple Access (OFDMA) based networks, adaptive to various channels and signal conditions, and based on standards that comprise a framework allowing significant change and extension without breaking, an approach now looking obvious.

However, although several telecom advisers are predicting a convergence towards a NGMN concept as depicted in Figure 3, there are various reasons to believe that their coexistence will continue for several years to come.

3.2 *SatCom systems*

MarCom's objective is to find appropriate SatCom solutions to complement terrestrial technologies, mainly beyond their coverage – and the most suitable are hence being sought among systems utilizing GEO, LEO and HEO orbits (see Figure 4).

A GEO satellite appears to be in a fixed position to an earth-based observer, since it is revolving around the Earth at a constant speed once per day at an altitude of about 36.000 km over the equator. 3–4 satellite constellations are generally used to obtain nearly 'global' coverage – however excluding a.o. the polar regions (!).

Inmarsat is internationally recognized as pioneers in mobile satellite services, being founded 30 years ago to ensure that ships could stay in constant touch by telephone via GEO satellites.

Over the years Inmarsat has continued to introduce new technologies and services, particularly to the maritime community: Inmarsat-A, -B, -C, -M, Mini-M, GAN, -D/D+, MPDS and the Fleet family (Fleet77, 55 and 33), based on older technologies termed "Existing and Evolved", mostly providing fax/data services with rates up to 9.6 kbps and medium/'high' speed data up to 128 kbps.

Recently Inmarsat introduced the novel BGAN concept, which benefits from the new I-4 satellites to offer a shared-channel IP packet-switched service of up to 492 kbps, and a streaming-IP service from 32 to 256 kbps. The BGAN family includes Fleet Broadband, a service planned for ships and the maritime community.

Another GEO-based alternative is represented by the various VSAT systems, utilizing satellite stations with typically dish antennas smaller than 3 m in diameter (most VSAT antenna diameters ranging from 75 cm to 1.2 m) to obtain data rates generally from narrowband up to 4 Mbps (46 Mbps being presently the fastest one [7]).

DVB-RCS represents a novel broadband VSAT-type multi-user design included in the Digital Video Broadcasting (DVB) family, and thus being the only open international standard for satellite networks with two-way communications, providing high capacity towards the user ($\sim$40 Mbps downlink) and more moderate capacity from the user ($\sim$2 Mbps uplink). DVB-RCS technology allows for star and mesh topologies with 10.000's of VSATs per network. Over 100 DVB-RCS systems are operating worldwide today – going mobile with handover from satellite to satellite, and numerous trials including train-, aircraft- and vessel-mounted terminals.

The only seemingly interesting LEO alternative is the Iridium constellation, using 66 cross-linked satellites in near polar orbit inclined 86.4° to the equator at an altitude of 780 km – and accordingly an orbit period of about 100 minutes – providing allegedly 'true' global coverage.

The nominal data rate of an Iridium 'channel' is 4.7 kbps, with latency for data connections about 1.8 s (round-trip) using small packets [8]. Iridium is also advertising a "Direct Internet" at 10 kbps, but this throughput is seemingly attainable only with compressible data subjected to Iridium's proprietary (remote) compression software.

The recent service offered by Iridium is OpenPort, claiming IP-based data rates of 9.6–128 kbps (configurable), featuring allegedly global gap-free, pole-to-pole coverage, with low-profile omnidirectional antennas independent of stabilization platforms.

Iridium is also planning a new generation of satellites – 'Iridium NEXT', to be operational by 2016, and expected to provide date speeds up to 1 Mbps (transportable K_a-band up to 10 Mbps (?)) [9].

Contrary to GEOs and LEOs the HEOs are characterized by a relatively low-altitude perigee and a high-altitude apogee. These elongated orbits have the advantage of long dwell times near a point in the sky during the approach to and descent from apogee – a phenomenon known as the 'apogee dwell' in accordance with Kepler's second law. The orbital eccentricity is adjusted to the rotation of the Earth in order to make the satellites operating near the apogee and moving with nearly the same speed as the Earth, thereby maintaining a fixed position in relation to a point on the ground.

During the early 1960's Soviet Union aerospace engineers devised the Molniya HEO, which is simulating the convenience of a GEO while simultaneously servicing the extreme northern regions, with an inclination of (ideally) 63.45° relative to the Earth's equatorial plane, and an orbital period of ½ a sidereal day. During this orbital period the Earth makes ½ a turn, and thus the apogeum will be at the very same position relative to earth twice a day. Seen from the Earth a Molniya orbit satellite will thus apparently be in zenith about 39.750 km above two positions (at latitude 63.45° – see Figure 5) during roughly 8 hours twice each day, the perigee height being only about 500 km. Accordingly 2 satellites would provide continuous coverage of the northern hemisphere, but a 3-satellite constellation is preferable [10].

Apart from the evident Russian applications, several studies on utilizing Molniya orbits for quite a few applications have been carried out, recognizing their apparent benefits in:

- Providing a quasi-stationary perspective with an apogee height approximating the GEO, and thus GEO technologies can be reused (slightly modified) to a.o. reduce costs and risks

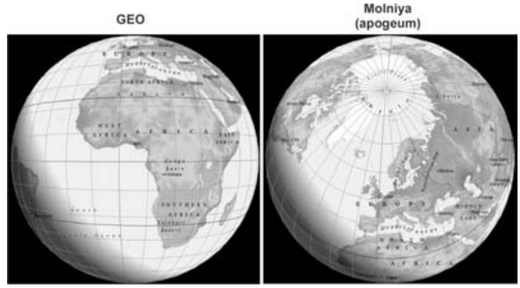


Figure 5. The Earth seen from GEO and HEO (Molniya) satellites, respectively.

- Giving an optimum high-latitude coverage per satellite with no LEO-like latitudinal coverage gaps, and little time "wasted" over lower latitudes adequately seen from GEOs
- Simple ground segment; real-time communications can be achieved with a single primary ground station, as for GEO
- More cost-effective than GEO systems for the delivery of satellite-based mobile multimedia in Europe [10].

However, an inconvenience with the Molniya orbit is its satellites passage through the 'van Allen radiation belt' twice per revolution, requiring additional mass to obtain protection of e.g. the solar panels.

Another attractive HEO avoiding this hindrance is the more low-eccentric '24-hours' Tundra orbit, which is more comprehensively described in [1].

4 THE HIGH NORTH CHALLENGES

The fragile environment of the High North is decidedly dependent on a sustainable ecosystem balance. Safeguarding this balance calls for a highly developed communication infrastructure and sophisticated surveillance systems, which are presently unavailable. Reliable broadband radio communications in the Northern and Arctic Region is vital for fast reporting of status and evolution of the environment, and early warning of pollution threats. Additionally, these technologies are decisive for efficient handling of hazards and accidents intimidating people and/or the environment.

Broadband radio communications with data rates of several Mbps is anticipated to be needed by several activities in this vast area, out of which the more important are:

- Fisheries, including resource investigations and protection
- Oil and gas offshore activities
- Fishfarming, aquaculture installations and associated activities
- The Coast Guard's law enforcement of environmental crime and other illegal activities
- Homeland security and defense activities

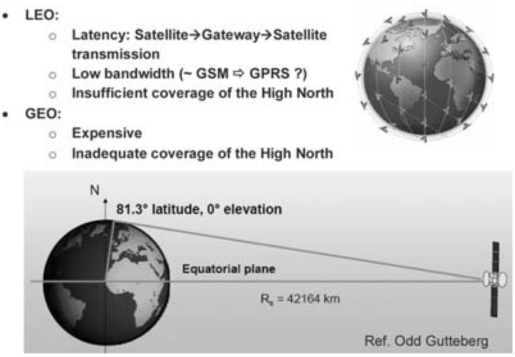


Figure 6. Traditional SatCom limitations in Polar regions.

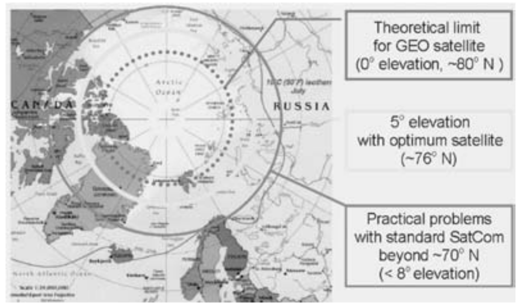


Figure 7. Illustration of the inadequate GEO coverage in the High North.

– Research activities (ice studies, meteorological and hydrological research and monitoring etc.)
– Coastal water activities (ferries, cruise ships, support ships, fishing, fishfarming etc.)

The terrestrial systems outlined in paragraph 3.1.1 needs further thorough investigations regarding feasible utilization in the High North, but the commercial aspects are most likely to override the technical challenges, since the initial number of users are supposed to be fewer than commercial operators would consider satisfactory.

However, our preliminary findings indicate the coastal areas (including the Northeast and Northwest passage) to be adequately covered by terrestrial systems, where sub-GHz WiMAX and enhanced D-VHF are considered the most promising alternatives. In order to cover the passage North of Russia or Canada, or the area near Svalbard, a "chain" of pertinent base stations with an appropriate backhaul infrastructure would be required. The cost and complexity of such a system would necessitate a detailed study of a.o. the area's topography. But even if such systems could be favorably deployed, vast areas would still be left uncovered, demanding other solutions to complement these coastal area systems.

The crucial limitations of traditional SatCom systems are illustrated in Figure 6:

– Although Iridium claims the OpenPort service to provide IP-based data rates of 9.6–128 kbps, featuring allegedly global gap-free, pole-to-pole coverage, this system is judged inadequate as a more permanent solution to the High North
– GEO satellites are invisible at latitudes exceeding about 80°N
– Even relatively advanced maritime SatCom terminals with stabilized antennas require elevation angles preferably >5°, and are thus rendered inadequate at latitudes exceeding about 76°N.
– Stabilized antennas must lock onto the intended satellite for proper operation, but several conditions, including the vessel's unpredictable gyrations, can instigate a stabilized antenna to drift from the intended satellite and cause signal drop-out and/or harmful interference to adjacent satellites. Due to rather severe roll, pitch and yaw movements of a vessel during adverse weather conditions even larger elevation angles are required, and thus practical problems with 'standard' SatCom terminals may be expected to arise at latitudes beyond about 70°N. Layers of (mixed) saltwater, sleet and ice on the antenna radome will certainly not diminish such problems, and thus adding up to the unsatisfactory situation illustrated in Figure 7.

Consequently it seems evident from our preliminary findings that HEO's would provide the only technically viable alternative for adequate SatCom's in the northern areas – in fact to the northern hemisphere on the whole (which accordingly also applies to the southern hemisphere if the orbits are 'reversed'). However, thorough investigations are required to reveal the cost/performance figures of pertinent systems, along with their success factors [1].

5 RADIO ENGINEERING CHALLENGES IN MARITIME ENVIRONMENTS

In order to meet MarCom's major objective of extending the coverage and range at sea for both in-use and novel terrestrial wireless technologies, several radio engineering challenges are to be met, such as:

– The characteristics of radio signal propagation over the sea must be known
– Appropriate frequency resources must be (made) available
– Improved antenna systems need careful attention
– Investigations of additional means to extend the coverage and range are required, such as:
  – Repeaters; passive, active and regenerative
  – Mobile Multi-hop Relay (MMR)
  – Mesh networking

The ability to accurately predict radio propagation behaviour for wireless services is becoming crucial to system design. Numerous studies have (unsurprisingly) been conducted for densely populated areas, but very few have been focusing coastal waters, which are exhibiting physical layer structures quite dissimilar to urban surroundings. Consequently reliable radio channel models for propagation over sea are required to make appropriate range/coverage predictions, and particularly to enable improvements of system performance by applying e.g. diversity and/or advanced antenna systems techniques. Both theoretical studies and experimental trials are required to determine such models.

The overcrowded radio frequency spectrum represents a crucial challenge to wireless services in general, and to maritime applications in particular.

However, ITUs World Radiocommunication Conference 2007 (WRC-07) approved the identification of the 450–470 MHz and 698–862 MHz frequency bands for International Mobile Telecommunications (IMT) services. These frequency bands are being referred to as the ‘digital dividend’ – the freeing up of spectrum brought about by the terrestrial TV distribution switch from analogue to digital technology.

These frequencies are also being referred to as a part of “the spectral sirloin”, since, in addition to exhibiting attractive propagation characteristics, they also facilitate relatively undemanding development and low-cost production of RX/TX radio equipment with reasonable size and weight. The upper UHF band (698–862 MHz) is thus a target band for the WiMAX Forum, and the earliest applicable (reconfigurable) sub-GHz WiMAX products are already commercially available [5].

The utilization of these sub-GHz frequencies would facilitate the novel wireless terrestrial systems extension of coverage and range at sea, which is illustrated by the fact that e.g. covering the same area require only 2 base stations at 450 MHz compared to 30 at 3.5 GHz [5] – i.e. also an economical advantage factor of about 15 (!), and thus being highly beneficial to maritime applications.

However, each country has the authority to manage their frequency resources, and an international harmonization would consequently be needed to provide the maritime community with the most favourable solution.

Antennas (and RF transceivers) comprise crucial sub-systems to any radio system. Numerous antennas presently being applied in wireless systems are rather outdated, and accordingly system performance can be significantly enhanced by utilizing more sophisticated antenna designs. Emerging smart antenna technologies also enabling cost-effective shipborne solutions represents an area to which extensive R&D resources should definitely be allocated.

Other means to enhance range/coverage are Repeaters, MMR and Mesh networking, all referring to different concepts for conveying user data, and possibly controlling information, between a base station and a mobile station through one or more relay units – to be utilized along with the other appropriate

Figure 8. Illustration of the suggested ‘Wireless Coastal Area Network’ (WiCAN) concept.

techniques and methods discussed in this paper to realize the suggested ‘Wireless Coastal Area Network’ (WiCAN) concept illustrated in Figure 8 [1].

In order to facilitate seamless and continuous handover and roaming within the heterogeneous WiCAN environment, a ‘smart mobile router’ would represent a crucial component, having been termed an ‘Agile MarCom Communication Adapter’ (AMCA) in the MarCom project.

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7.6
Advantages of preservation of obligatory voice communication on the VHF radio channel 16

S. Brzóska
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: Channel 16 of the VHF radio band is the most commonly used way of communication between vessels. Although there are strict rules not to use it for routine communication, many officers neglect them. When Digital Selective Calling had been presented to the GMDSS system, it was no longer obligatory to keep a watch on channel 16, however, on the waters of the United States such an obligation is still in force. Officers find DSC system quite difficult to use so the European countries should revise their politics and consider restoration of obligatory watchkeeping on channel 16.

1 VHF RADIO USAGE ACCORDING TO INTERNATIONAL CONVENTIONS

1.1 *SOLAS obligations for VHF radio equipment*

The SOLAS 74/02 Convention states that each vessel of Gross Tonnage 300–500 should carry at least 2 VHF radios while every passenger ship and every cargo vessel of Gross Tonnage more then 500 should carry at least 3 VHF radios on board (SOLAS, 2006). VHF radios should not only be present at the bridge, but also be properly situated. Headset should be in the vicinity of officer's hand and the speaker near his ears. Ship's wings should also be fitted with VHF radio equipment to be use in emergency situations or simply during manoeuvres.

The SOLAS states that there should be at least 2 separate ways to communicate in distress situation. One of them is always VHF radio, since it is obligatory to carry it when ship is operating in the A1 Sea Area and so in all other areas (ALRS 5, 2007/08).

VHF equipment consists not solely of a speaker and a headset. It is permanently connected to the Digital Selective Calling device operating also in the VHF band. The DSC device is capable of sending and receiving DSC messages. The messages are sent with a usage of 156.525 MHz frequency (channel 70). Monitoring on the VHF frequencies should be continuous on the DSC channel 70 and broadcast channel 16. SOLAS requires VHF radios to send and receive communication on frequencies 156.300 MHz (channel 6), 156.650 MHz (channel 13), 156.800 MHz (channel 16) as in Table 1 (ALRS 5, 2007/08).

1.2 *STCW obligations for VHF radio users*

VHF radio operators should have proper GMDSS qualifications (Walczak, 1996). At least the General Operators Certificate (GOC) should be held by the officer who is keeping a navigational watch on a bridge and uses the GMDSS equipment. The STCW Code (STCW Code, 2001) states, that the radio watch shall not be disturbed by any communication not connected with safety of ship and navigation so any routine or private communication during watch is forbidden.

Table 1. VHF radio channels required by the SOLAS.

	Frequencies (MHz)		
Channel	ship	shore	Special purpose
6	156.300		SAR communication
13	156.650	156.650	Safety of navigation
16	156.800	156.800	International distress, safety and calling
70	156.525	156.525	DSC

2 ADVANTAGES OF THE VHF BAND

2.1 *VHF range*

English "VHF" abbreviation stands for Very High Frequency and it describes those waves of the electromagnetic spectrum which length is a multiplicity of meters. We can easily describe electromagnetic waves as a self-propagating radiation. The term "propagation" explains how the radio waves behave in a vacuum or in a matter when they are transmitted. The propagation may be affected by many phenomena like refraction or absorption.

Of all the ways that the electromagnetic waves can propagate, those which are attached to the VHF band (30 MHz to 300 MHz) propagate in an accurate, but somewhat short way – with a use of a direct mode or a "line-of-sight" mode. The term comes from the fact that a VHF frequency wave propagates between antennas that are visible to each other. It is not exactly true, because of the air humidity and an effect of refraction, the VHF propagation is somewhat farther then the line-of-sight and is assumed to be more or less 30 Nm (Czajkowski, 2002).

It is rather an advantage then a disadvantage that VHF waves propagate in a circle of only 30 Nm from the sending station. Thanks to that fact a sender might be sure that his message will be sent only to stations in his line-of-sight and only those, who are really concerned about his message, will get it.

2.2 *VHF channels*

In maritime radio communication the wave-bands are marked by the letters. The maritime VHF band range is between 156 MHz and 174 MHz and is marked by letter "V". In that range of frequencies separate channels have been divided. The separation between channels is usually 25 kHz with an exception for 12.5 kHz division if local authority finds such a division necessary (ALRS 5, 2007/08). To make the usage of VHF channels easier, they have been marked with 2 digits. Instead of entering a long numbered and hard-to-remember frequencies (like in the MF/HF devices) user can simply enter 2 digits and the VHF radio will be tuned to the proper frequency.

2.3 *The VHF communication rules*

Finding usage of the VHF radio so easy makes it the most practicable tool for marine communication in the world. VHF radios are user-friendly devices, similar to cell phones, which are nowadays used by almost everyone. A well qualified user (e.g. a holder of the GOC certificate) should have no problem with VHF voice communication. He simply needs to know some basic rules, implemented in the "Seaspeak", Standard Marine Communication Phrases (SMCP), International Code of Signals and Admiralty List of Radio Signals. Basic rules e.g. implemented in the "Seaspeak" are:

– don't make unnecessary calls,
– use proper procedures,
– use proper channel,
– speak slowly and fluently,
– avoid disturbance of other calls (Weeks, 1984).

If the officers would fallow these rules there shouldn't be any problems or mistakes in the VHF communication. Unfortunately, maritime courts often find misusage of the VHF radio as a cause of a collision or a marine accident. VHF radio equipment cannot be blamed for that. It's usage is so easy that the only ones to blame are the officers themselves. Among the typical mistakes they make are:

– not applying to communication rules of the SMCP and "Seaspeak",
– language mistakes, especially those caused by little English knowledge,
– wrong identification of vessels, e.g. not using names, call signs, MMSI numbers,
– keeping conversation on channel 16 or channel restricted for VTS communication.

Little English knowledge is becoming a problem. Since many maritime schools and training centres lowered their requirements for the candidates for future officers the level of education has also been lowered. They rarely follow SMCP and "Seaspeak" rules and when the rules are disobeyed it may lead to a disaster. The "weakest chain" in the maritime communication system is again the "human factor".

As it was already said the VHF radio equipment is easy to handle. However, when it comes to the DSC VHF system, which is connected to the voice-broadcast VHF device, it becomes much more complicated.

2.4 *Digital Selective Calling on the VHF band and it's disadvantages*

Digital Selective Calling was introduced to the GMDSS system on MF, HF and VHF bands. It was intended to make easy, automatic communication with shore stations and other vessels. DSC device can either send automatic messages, like distress message (by simply pushing a "distress" button for 5 sec.) or recently prepared messages by the officer in charge of a navigational watch. The preparation is done only by choosing (Czajkowski, 2002):

– format specifier (distress, individual, geographical area, all ships, groups),
– MMSI number of the receiving station (not necessary if the message is addressed to "all stations"),
– proper category (from listed: distress, urgency, safety and routine),
– special information (e.g. about nature of distress, from listed: piracy, sinking, listing, fire on board, etc.).

So it is not possible to send a typed message, like a cell phone's SMS.

The DSC system works perfectly well when it comes to a distress message. The only thing the operator needs to do is push the right button for a fixed amount of time and the message will be sent automatically. The user problem appears when it comes to preparation of a more complicated message. The DSC equipment panel is not as user-friendly as was the VHF voice communication device. In fact is rather user-unfriendly system. The ITU Regulations are very complicated and it is difficult for an officer to remember when he can and when he cannot send confirmation of a distress. Preparing a message is also quite difficult, especially with a device's display consisting of two lines of black and white text. People who nowadays work on the Personal Computers (PC) which has big, colourful screens, with wide windows and easy-to-choose options, find DSC equipment somehow old-fashioned. Officers are often afraid to use the DSC equipment because they don't comprehend all the rules and the device itself.

In the times when there are 3.3 billion operating cell phones in the world and thus every second man on the planet has a cell phone (Kobel, 2007), wouldn't it be easy to change DSC messages into user-friendly SMS system like the one in the GSM net?

2.5 *DSC watch keeping obligation*

The SOLAS convention states that monitoring on the VHF frequencies should be continuous on the DSC channel 70 and broadcast channel 16, however, in special areas, like VTS, local authorities can recommend their own broadcast channels for watch keeping.

DSC was intended to eliminate the need of keeping continuous watch on radio receivers on voice radio channels, including VHF channel 16. After 1 February 1999, according to SOLAS, every ship had to keep continuous watch on channel 70 simply with having such a device on board. The DSC receiver works automatically – when a message comes a buzz-signal is sound. The officer simply needs to push appropriate button, read the message and tune the radio to the right VHF voice channel (recommended in the message itself) and wait for the communication to come.

Thanks to the DSC system it is certain that the recipient will receive the message because the message is stored in the device and can be read in any time. That's the main advantage of the DSC system. With voice communication, when officer is busy and cannot lift the headset, the message broadcasted by voice might not be received. DSC message comes whether he likes it or not – it is stored in the device, just like SMS message is stored in a cell phone. To make the sending station sure that the message came, receiving station can send a confirmation (however it is forbidden to send such a DSC confirmation to a distress message from a ship, because then the message might not get to the appropriate SAR station).

3 VHF COMMUNICATION ON CHANNEL 16

3.1 *Legal issues concerning channel 16*

Despite the above mentioned advantages of DSC system it is still practised to keep a listening watch on the VHF channel 16. It is a good seamanship to do so and here it is where the rules are not complying with the practise. SOLAS convention states in chapter IV/12 that "*Ships 300 tons and over and passenger ships on international voyages must maintain, where practicable, a continuous listening watch on VHF channel 16 until 1 February 2005"* (SOLAS, 2006). In May 2002, IMO decided to postpone cessation of a VHF listening watch aboard ships until 1 February 2005. In ITU Regulations there is a statement: *"All ships should, where practicable, maintain watch on channel 16 when within the service area of a VHF maritime coast station (ITU, RR 38-16)*. So there is no longer strict obligation to do so. The statement "where practicable" in both SOLAS and ITU Regulations might be read as an admittance for not listening to the channel 16. For example, in places where both VTS and harbour master are using channels different than 16 (e.g. in Gdynia harbour ships are listening to channel 71 for VTS Zatoka and 12 for Gdynia harbour master), a ship with two VHF radios may not listen to the 16 channel at all.

The problem comes with a small pleasure crafts, fishing vessels and sailing vessels, with low-qualified crew, who are often not listening to the VTS channels or 16 channel or are absolutely disobeying the Rule 5 of the COLREGS "Look-out" (like the skipper of "Our Sarah Jayne" the case of which is described in the next chapter of the paper).

When a disaster comes, because of not listening to 16 channel and not responding to a call, the captains of such vessels might afterwards explain themselves that they were not obliged to do so. The communication between vessels would be much easier if there was still an obligation to listen to the 16 channel. Not "where it is practicable" but everywhere, e.g. with a usage of the "dual watch" availability of the VHF radio.

Such a problem does not exist in the United States because the US Authority – Federal Communications Commission – stated that *"any vessel equipped with VHF marine radiotelephone must maintain a watch on channel 16, whenever the radiotelephone is not being used to communicate"* (FCC: Title 47). The usage of word "must" grants that officers will keep a watch on channel 16.

3.2 *Using "dual channel" option*

Thanks to the common sense of the officers and "dual channel" options of the VHF radios the watch on the channel 16 is still kept. "Dual channel" is an option included in the VHF radio device which enables to listen to two channels in the same time – e.g. channel one for 1 sec. and the other, main, for 9 sec. When a message comes or any voice signal on one of those channels is received the receiver tunes itself automatically to that channel.

It's a very useful tool to use especially on those ships which are equipped only with 2 VHF radios (vessels of GT less than 300) or vessels which are carrying radios voluntary because they are too small to take part in the SOLAS convention. Those small vessels, most of which are pleasure crafts, are usually carrying VHF radios and for them it is the only way of communication.

4 PROBLEMS WITH DISOBEYING COMMUNICATION RULES

4.1 *Disobeying the Rule 5 "Look-out" of the COLREGS*

The Rule 5 states that *"every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a* *full appraisal of the situation and of the risk of collision"*, VHF radios are one of those mentioned as "all available means" (Rymarz, 2004).

So not only SOLAS and ITU-R but also the Collision Regulations demands keeping a watch with using VHF radio (even if it is stated as "all means").

Disobeying the rules may lead to a collision. The officer had to be focused on all aspects of the navigation. He needs to have a whole view of the situation. To keep his full attention he needs to maintain proper look-out and "proper" means "full". If in any case he is not sure of what is going on he must have an always ready-to-use tool to solve the situation. VHF radio is such a tool and it's proper usage can be as simple as keeping watch on channel 16.

If the officer neglects usage of that tool he may cause a marine accident, just like the "Our Sarah Jayne's" skipper did.

4.2 *Collision between "Thelisis" and "Our Sarah Jayne" as a result of disobeying Rule 5*

On 20 June 2001 in the Thames Estuary two vessels collided. One of them was the 8904 gt Greek-registered ro-ro cargo vessel "Thelisis" and the other was small registered fishing vessel "Our Sarah Jayne" which was only 14 m long. At the time of the collision "Thelisis" was under pilotage and "Our Sarah Jayne" was engaged in fishing (MAIB, 2002).

"Thelisis" was plying through Princess Channel and spotted a white light in front of her bow. Both pilot and the master were not sure of the source of the light. The pilot called VTS to receive information on the object, but the VTS operator also didn't know what it was. When the range between ships was around 1 Nm "Thelisis" recognised the object as a fishing vessel and tried to call him on VHF channel 12, the channel which was used by the Thames VTS in the area. Because of wrong identification first he came into communication with other vessel and started to agree manoeuvre. The pilot was sure that the fishing vessel would give way and she did not.

"Our Sarah Jayne's" skipper was not aware of the imminent danger until the collision took place. That was because he was completely disobeying the Rule 5 and was not keeping any look-out at all. He had his VHF radio on and tuned to VTS' channel 12, but the volume was set midway. He left the wheelhouse unattended many times and probably didn't hear any calling and even if he did heard them he was not aware that he was the one referred to.

"Our Sarah Jayne" flooded then foundered almost immediately after the collision. The skipper was rescued by a Thames pilot cutter.

5 CONCLUSIONS

Since VHF radio is such a useful tool and neglecting it might be so dangerous the Authorities should encourage deck officers to use it. The channel 16 should be on at all times and a continuous watch should be kept. DSC communication is helpful but it shouldn't be the only recommended way of communication because of it's disadvantages mentioned in the paper. Mostly because DSC devices are complex and not at all user-friendly. If the local authorities require keeping a watch on different channels then the "dual watch" option should be used or even another VHF radio installed onboard. The international regulations should again expect the officers to keep a channel 16 watch, like it is practicable on the United States waters.

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7.7 The transmission of the information of the system of telecommunicational DECT in the trans-shipping terminal

A. Kuśmińska-Fijałkowska & Z. Łukasik
Technical University of Radom, Radom, Poland

ABSTRACT: Introduce the concrete project of the distribution of base stations in the article and propose the architecture of the system DECT of the trans-shipping terminal. The simulation of the system of DECT which was limited only to the broadcasting track from the transmitter to receiver set was realized he walks about examining the quality of the radio broadcast between the base station, and the station movable. It was accepted as the criterion of the quality the bit error ratio (BER) during the of sending given broadcasts.

1 INTRODUCTION

Serious difficulties exist solving many questions of the theory of the telecommunicational movement analytic methods. The way of behaviour can be the signal one of examples of such problem in the broadcasting track. Presented questions can real system, his physical or simulating paternal be solved by the observation. He complies first method only in the limited range because of high costs. He often also wants to become acquainted the motive proprieties of the system being just in the bevel of projecting. You should understand the techniques of solving the problems consisting in the observation during changes drawing ahead in the dynamic paternal of the system by the simulation.

The creation of paternal brings in many advantages for the explorer of the system (Filipowicz 1996):

- checking the theoretical courts about system, accomplishment on the model of empirical observations and extraction from these actions of logical conclusions makes possible,
- the understanding of the system facilitates,
- he makes possible the opinion of the meaning of the details of the system and the relationships of boundary strip them,
- the realization of the analysis accelerates,
- he makes up the basis of the opinion of the advisability of the modification of the system,
- it is more easily before to manipulate than the system,
- the model is, in the general case, expensive the than system less.

2 SYSTEM DECT FOR SETS PARAMETERS

In the aim of designing the system of DECT for trans-shipping terminal, you should execute the suitable measurements of the field and the conditions of the propagation of waves on him and work out on their basis the project of the distribution of the station base RFP so that where the ranges of these stations cover the whole terrain the system DETC has to function (Jackowski 2005). The result of this working was introduced on Figure 2.2. Red dots mark points, where you should place base stations so that they their range cover the whole terrain. For considered earlier parameters and it was affirmed for the given configuration of objects that you should use 16 base stations. The number of the station probably underwent the change after executing specialist measurements. The ideological pattern of the proposed system was introduced on Figure 2.1.

It is the most suitable system to put earlier parameters the multicellular system of the contact radio Hicom cordless E. The system integrated of wireless contact co-operating with central stations ISDN Hicom 300 E and Hicom 300. The architecture of the system and digital broadcast leaning on the standard of DECT guarantee the free contact in buildings and their surroundings. Stations base RFP are added for the help of digital interfaces to integrated with central station modules. He possible is thanks to this projects and carries out the installation of the system of the radio,

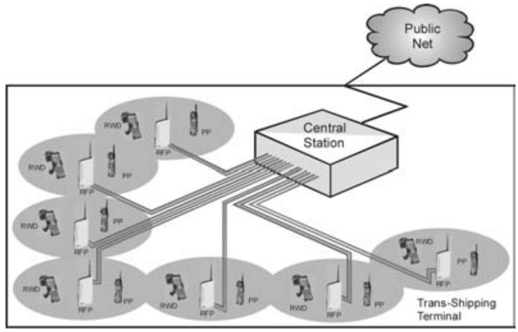

Figure 2.1. The scheme of the system of DECT (own study).

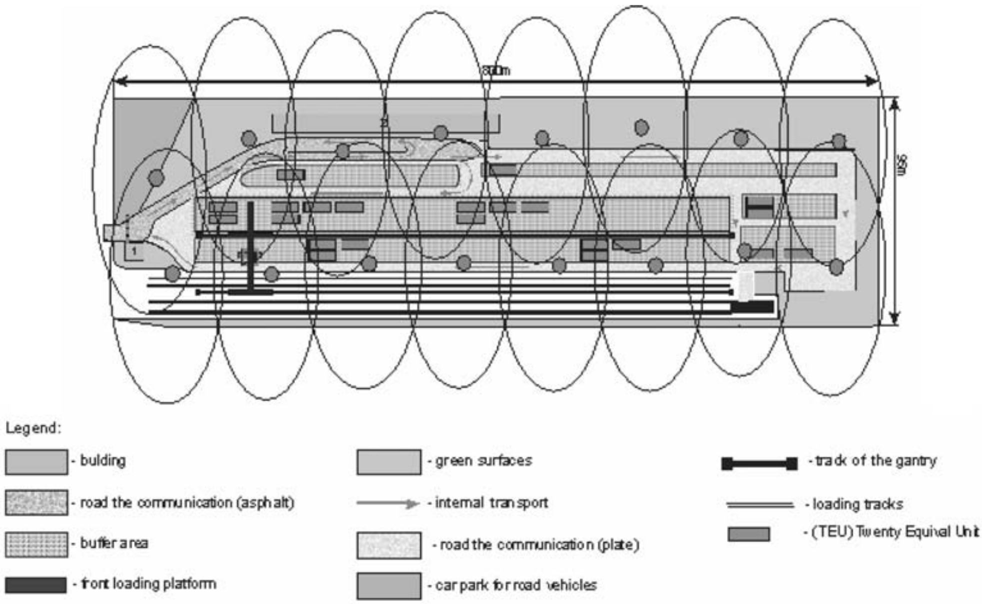

Figure 2.2. The plan of the distribution of base stations and their radio ranges in the trans-shipping terminal (Kuśmińska-Fijałkowska 2008).

Figure 2.3. Base stations P-2302HWUDL-P1.

Figure 2.4. The wireless receiver (PP).

optimum contact under in relation to costs, area of range and users (PP) number (Figure 2.4). He assures apparatus Gigaset 3000 (PP) roaming between various systems and lets use the function of central station Hicom 300/300 E. System will make possible constructs connections and receiving developments on the whole terrain the covered radio range.

Base stations create radio mobile phones for the needs of the wireless contact on the area trans-shipping terminal. They convert the radio signal on the signals of the interfaces of DECT and WLAN integrated with central station base ISDN 300/300 E. They can be reinforced from her or from the external source of the voltage. The location of base stations is defined after executing the measurements of the field and radio conditions and worked out on their basis of project (Figure 2.2). (Łukasik 2007)

Proposed device (base station) this P-2302 HWUDL-P1 (Figure 2.3), which WLAN is equipped in the interface Ethernet 10/100 Mbps, working in the standard 802.11 b/g and two the port USB the enabling facility in the net of the printer or memory of the mass VIP possesses the integrated gate with the base station for the receivers of DECT (PP).

3 THE SIMULATING MODEL OF THE SYSTEM BROADCAST SIGNALS OF DIGITAL

The simulation will be conducted in the programme Matlab Symulink, he will be realized only for chosen his part. She oneself will base on examining the quality

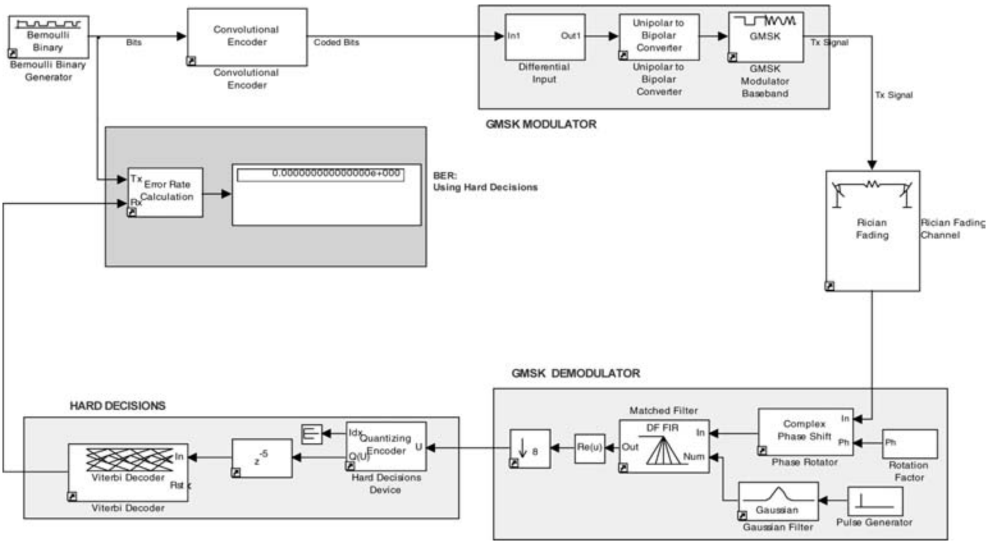

Figure 3.1. The pattern of arrangement to the measurement of the bit error ratio (own study).

of the radio broadcast between the base station, and the movable station (PP).

The bit error ratio was accepted as the criterion of the quality during the of sending given broadcasts (Wesołowski 2003) The simulation will be conducted for three variants:

1 The movable station is inside the building.
2 The movable station is beyond the building and moves with the maximum speed even 5 km/h.
3 The movable station is the building outside and moves with the average speed even 20 km/h.

The pattern of the measuring arrangement of the bit error ratio (BER) for the chosen part of the system was introduced on Figure 3.1. He will look for the various variants of the simulation, only parameters of the radio track will change. The effect Doppler will not be taken into account in first case, and only hums introduced through channel and phenomenon multiways of the signal. The phenomenon Doppler was considered in the next case for the set speed. These alone phenomena will be considered in the last case, what in second case with this, that the phenomenon Doppler will play the significant part.

He is on the entry of the arrangement passed the random binary draught from the generator Bernoulli. Probability of the pronouncement 0 and 1 carries out 0,5.

The draught crosses from the generator to the encoder the channel, which complies to improve or, what the least affirm of the existence of mistakes in the binary sequence. Informative bits are replenished about certain quantity of suitably well-chosen additional bits 2 chosen informative bits beaten these are the sum the modulo. Algebraical dependences come into being among bits in the sequence in such way so that the error of some lets on reproducing the original sequence been useful from them in this way. The signal is steered to the modulator GMSK then. The modulator is the arrangement generates the signal modulate, whose parameters such as the frequency, amplitude and bevel are the function passed on his entry of the binary draught. Thanks to what the signal carrying information binary is placed in the proper strand of the frequency and has the shaped spectrum suitably. The radio signal after passing through the channel grinds in to the receiver set which consists of these alone blocks what the transmitter, but every block realizes the opposite function than in the transmitter. The block “Rician Fading Channel” was applied for first case of the simulation in the radio channel. White gaussian noise adds block this the hum to the entrance signal and the multiways of the signal takes into account. One can skip the phenomenon Doppler in the building.

The small frequency Doppler was considered in second piece of the simulation in the radio channel. Simulating arrangement for third case differs from second these that the maximum shift Doppler carries out 35 Hz (for the of the station of the movable-cart jacks even speed 20 km/h), it carried out approx. 7 Hz in the previous case where.

3.1 *Got results*

Changing the values E_b/N_0 was noted down the value of the bit error ratio. She was different for various E_b/N_0. Dependences what were got it was introduced on Figure 3.2.

The next stage of the simulation is the measurement of the bit error ratio in dependence from the speed of the mobile station. This was realized changing the frequency Doppler which answers the value of the speed near the solid value E_b/N_0. Enumerated speeds were introduced in Table 3.1 for the chosen frequencies Doppler which was used during the simulation.

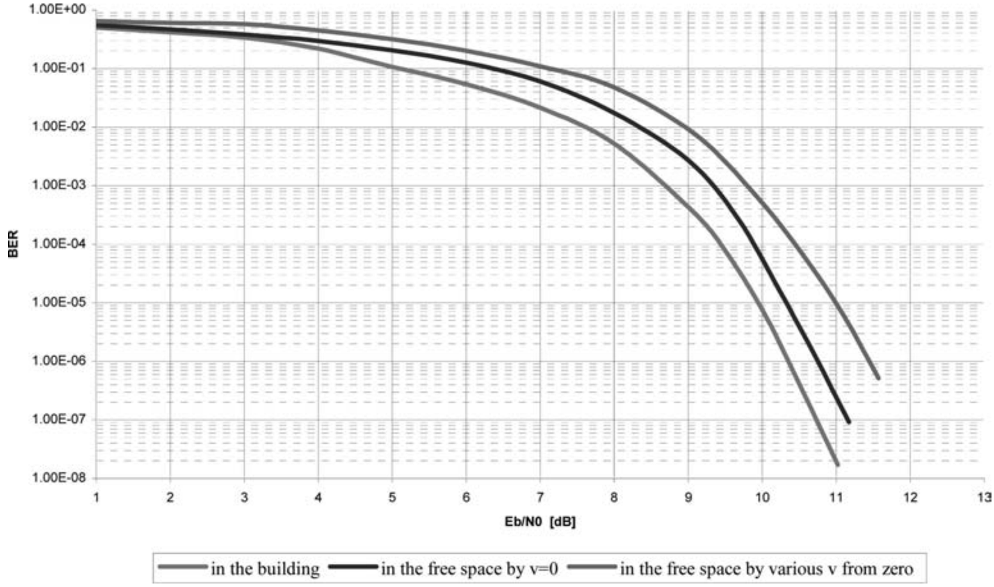

Figure 3.2. Dependence BER in the function E_b/N_0.

Table 3.1. The counted values of the speed for chosen frequencies Doppler.

Frequencies Doppler [Hz]	Speed [km/h]
0	0,0
5	3,1
10	5,7
15	8,5
20	11,4
25	14,2
30	17,1
35	19,9
43	24,4
47	26,5
48	27,5
60	34,1

4 CONCLUSIONS

Could was the system of the wireless contact leaning on this standard design, the hypothetic plan of the distribution of objects was created on the terrain trans-shipping terminal. It was considered in the structure terminal that the system of the exchange of information (DECT) should function inside objects, in the free space (the article pt. "Propagation FEM on areas about the folded architectural structure the trans-shipping terminal") and during subscribers movement mechanical vehicles (Gate Gantry, Sisu). Wanting approach to the distribution of base stations on the introduced plan trans-shipping terminal analyze propagation FEM and qualify the ranges of base stations inside objects how and on the free space. Introduce the concrete project of the distribution of base stations after qualifying maximum ranges and propose the architecture of the system of DECT in the trans-shipping terminal. The aim of the verification of the correctness of functioning of the proposed system of DECT, the realized simulation was introduced in the programme Matlab Symulink.

In first variant of the simulation changing the values E_b/N_0 was noted down the value of the bit error ratio. She was different for various E_b/N_0. Dependences what were got they are introduced on Figure 3.2. According to the recommendations of the standard of DECT the bit error ratio, for $E_b/N_0 = 10$ dB, he should carry out 10^{-5}, and the sill timber of the receipt finds oneself in BER $= 10^{-3}$ (Kuśmińska-Fijałkowska 2008). As one can read value this from Figure 3.3 for conditions in the building he carries out approx. 10^{-5} and together with the growth E_b/N_0 diminishes quickly. However for second case, i.e. on the open space, the value of the bit error ratio grew up considerably and carries out for 10 dB 10^{-4}. This caused these is, that the distance of between the transmitter, and he is the receiver set considerably larger than in buildings and the worsened quality of the receipt of the data becomes. Third value of the bit error ratio was in the variant approx. 10^{-3}. Value this in the comparison from previous he is considerably worse, but he still is comprises in the foundations of the standard. The result which was got was caused these, that she was considered the maximum frequency Doppler, which as you can see, the quality of the broadcast worsened considerably. It is also with the phenomenon Doppler connected the maximum speed of movable stations in the system of DECT.

One can find in the foundations of the standard of DECT, that the maximum speed of movable stations

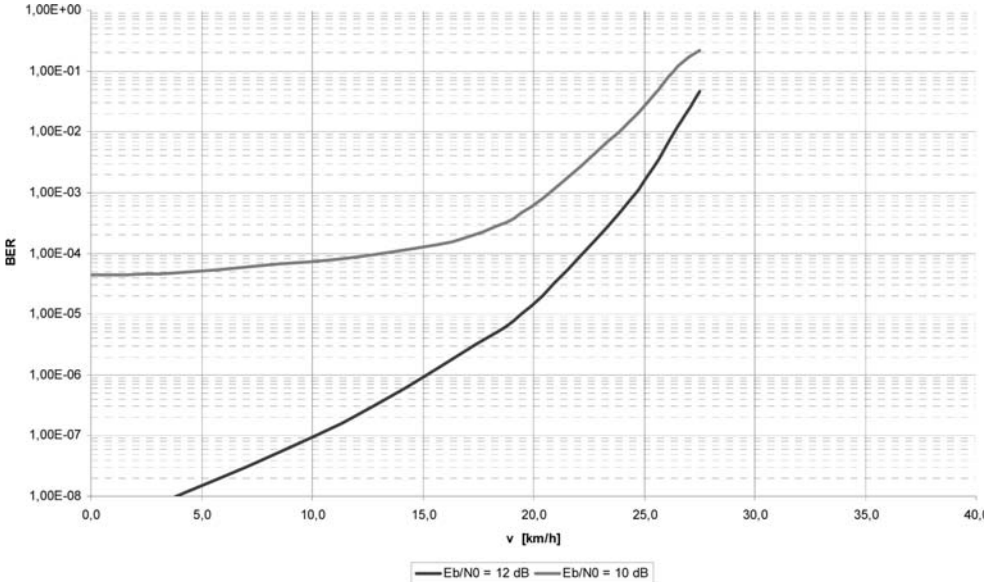

Figure 3.3. Dependence BER in the function of the speed of the movable station.

should not cross 20 km/h (Jackowski 2005). This caused these is, that for such fluxation he which offers DECT, shift larger Doppler than 35 Hz cause that the bit error ratio is not to the party by the standard and is comprises not in the sill timber of detection. max the speed of movable stations carries out 10 km/h in the case terminal. On Figure 3.3 was introduced the dependence of the bit error ratio in the of the speed of the station movable function. The simulation was conducted for two values $E_b/N_0 = \text{const}$. In first case the value E_b/N_0 accept even 12 dB. As one can notice the bit error ratio even 10^{-3} on Figure 3.3 it was got for the speed carrying out almost 25 km/h. He is caused this, that the relation of energy falling on the single bit to the spectral thickness of the power of the white hum additive he is enough large and can thanks to this get the larger speed $E_b/N_0 = 10$ dB was accepted in case second. As one can notice the bit error ratio is considerably worse in comparing with the previous profile for every speed. For BER carrying out 10^{-3}, the speed of the station of movable carries out approx. 20 km/h it would be the One from the ways of the enlargement of the maximum speed e.g. decrease of the fluxation of the system, like e.g. the enlargement of E_b/N_0. However one can not do this, because standard this was created for the assurance of the contact inside buildings, and not for movable stations moving with large speeds.

Results what were received, they could insignificant changes undergo near the investigation of the real system. This would be caused these that only several phenomena what had taken into account during the simulation they draw ahead in real radio tracks. The received results of measurements fulfil the standards of the standard of DECT, he infers from here that the designed earlier system of the contact will work according to foundations:

– he will assure the continuous understanding contact on the area of the dislocation terminal;
– he will make possible the realization of the digital summary contact of the short packets of information from the any object being on the terrain terminal;
– the sharp the tuning two-way socket will assure with external users both understanding as and in the figure of short telegrams, from the any external system;
– the information will be exchanged in the system of the contact protected before the access to her persons unentitled.

System DETC in the trans-shipping terminal will bring workers full mobility through shortening the time of the reaction, raise efficiency simultaneously, reduce costs and enlarging receipts trans-shipping terminal.

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Chapter 8. Manouvering and pilot navigation

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8.1 Navigational safety in SPM (Single Mooring Point) regions

V. Paulauskas
Klaipeda University, Klaipeda, Lithuania

ABSTRACT: For oil and gas transportation in some places used SPM (Single Mooring Point) system, this is located in the open sea and very often not so far away from the shore. Differences between the wind loads, waves and current forces can take a place. More complicate conditions can be in case if FSU is still in ballast and more influence has wind and waves as current and in the same time tanker in loaded position is more influenced by the current. Navigational safety ensure in SPM regions requests deep theoretical studies and very clear understanding of forces and moments, which influence on all the system (SPM, FSU, Tanker, tugs), practical implementation of proper equipment and use of correct methods of navigational safety. In this article there is made analysis of possible failures and necessary actions to ensure navigational safety in SPM regions.

1 INTRODUCTION

Navigational safety in SPM regions request deep theoretical studies and very clear understanding of forces and moments, which influence on all the system (SPM, FSU, Tanker, tugs), practical implementation of proper equipment and use of correct methods of navigational safety.

In case of FSU or tanker breakout (break towage-mooring rope) between SPM and FSU or FSU and tanker, in case of bad weather conditions, wind, waves and current starts pushing FSU or tanker, or both in outer forces direction and if this direction will be to the shore or other navigational obstacles direction, just very fast and correct actions must be taken to solve problematic situation.

Tugs bollard pull is important for the ships, which are using SPM in open sea for the daily operation and especially for the emergency conditions (BS6349, 2003; EAU 2004, 2006). Typical emergency conditions are investigated in cases, when FSU or tanker has technical problems and is necessary to assist for the FSU or tanker in safety region. In different situations and additionally in case of use of FSU and tanker, hydro meteorologically conditions has different influence on FCU and tanker and it requests actions for preventing accidents or other failure problems.

2 THEORETICAL BASIS OF THE NAVIGATIONAL SHIP'S HANDLING CONDITIONS

Typical emergency conditions in SPM regions mainly are linked with:

- Main engine or rudder failure, weather from reasonable to good;
- FSU or tanker breakout during bad weather.

Mentioned conditions are very important, because SPM position is in open sea but very often close to navigational obstacles (shore and shallow waters) and it is very important to have correct and fast answers regarding requested bollard pull and time stopping drift tanker and possibilities towage tanker or FSU away from dangerous places.

Theoretical Study was using three the main methods:

- Calculation method on basis Ship's Theory and Ship's handling in complicate conditions (V. Paulauskas, 1999);
- Simulation, used simulators, such as SimFlex Navigator (SimFlex Navigator Simulator, 2006);
- For the checking calculations and simulation results, to use experimental results from similar conditions, which take place on other real SPM places (SPM accidents investigation results, 2007).

Calculations were made by methodic, presented in references (V. Paulauskas, 1994; 1999 and 2004), and mainly were oriented on more complicate conditions, that means acting in one direction with some angles wind, current and waves, including shallow water effect.

Simulations were provided with equaling ships with recalculation to concrete planning ship in ballast and loaded and in same way on basis mass differences can made simulations and taken tugs forces (bollard pull).

Experimental results were taken from similar conditions, which were made by Author or from known references.

Constant wind component, as example, create forces, which can be calculate as follows (V. Paulauskas, 1999, 2004):

$$F_C = 0{,}5 \cdot C_a \cdot \rho_1 (S_x \cdot \cos q_a + S_y \cdot \sin q_a) \cdot v_{aC}^2 \qquad (1)$$

where:
C_a – aerodynamic coefficient, can be taken for such type calculations equal to 1 or can be taken for concrete ship, which model was tested in aerodynamic tube, data;
ρ_1 – wind density, for the calculations can be taken as 1,25 kg/m^3;
S_x – wind surface area on diametric direction;
S_y – wind surface area on middle direction;
q_a – wind course angle;
v_{aC} – average wind velocity.

Periodical forces can be calculated via acceleration as follows:

$$F_p = 4\cdot\pi^2\cdot t/(\tau^2)\cdot a\cdot\sin(2\cdot\pi\cdot t/\tau) \tag{2}$$

Finally periodical force can be expressed as follows:

$$F_P = F_P^{''}\cdot m, \tag{3}$$

where:
m – ship's mass;
τ – period of wind guess;
a – integration constant, which can be find as:

$$a = 0{,}25\cdot C_a\cdot\rho_1\cdot\Delta v_a^2(S_x\cdot\cos q_a + S_y\cdot\sin q_a) \tag{4}$$

Maximum forces, which can create periodical component of the wind, will be in case:

$$\sin(2\cdot\pi\cdot t/\tau) = 1, \tag{5}$$

and maximum periodical forces will be in case:

$$F_{P\max} = 4\cdot\pi^2\cdot t\cdot a\cdot m/\tau^2 \tag{6}$$

Waves constant and periodical forces can be calculate similar as wind loads as follows:

$$F_{wc} = 0{,}5\cdot C_w\cdot\rho\cdot S_x^{'}\cdot v_w^2\cdot\cos q_w, \tag{7}$$

where:
C_w – waves hydrodynamic coefficient, can be taken from [1, 2];
ρ – water density;
S_w – typical waves acting square;
v_w – waves spreading velocity;
q_w – waves course angle.

Waves periodical forces can be calculated similar as wind periodical forces, just in formulas (2)–(6) it is necessary to use wave's parameters.

3 PRACTICAL REQUEST FORCES CALCULATIONS

For the calculations is taken Suez Max tanker with next main dimensions: DWT – 183000 tons; length max – 274 m; length between perpendiculars – 264 m; width – 50 m; height (board) – 23,1 m; draft – 17 m (loaded); draft – 8 m (in ballast).

Suez Max ship's other dimensions in ballast: wind area S_x – 4500 m^2; wind area S_y – 1200 m^2; underwater area S_x' – 2100 m^2; underwater area S_y'S′y – 400 m^2.

Suez Max ship's dimensions loaded: wind area S_x – 2300 m^2; wind area S_y – 800 m^2; underwater area S_x' – 4500 m^2; underwater area S_y' – 850 m^2.

For the assistance were taken tugs with bollard pull 450 kN and 650 kN and were investigated FSU or tanker breakout during bad weather and Tanker main engine or rudder failure cases (Fig. 1).

Theoretical calculations results in case of acting wind and waves on loaded tanker are presented on table 1 and figure 2.

In case of FSU or tanker breakout during bad weather, especially FSU, because normally tanker can not be moored to FSU during bad weather, very important to find weather limitations for the planned tugs. To turn loaded FSU or tanker, 65 T bollard pull tug has

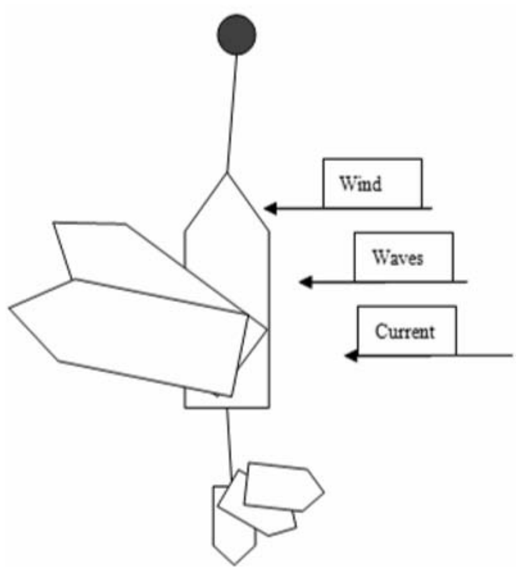

Figure 1. FSU or tanker breakout during bad weather.

Table 1. Wind and waves forces on the Suez Max loaded tanker, forces in T.

Wind velocity, m/s	Wind and waves course direction 0°	Wind and waves course direction 30°	Wind and waves course direction 60°	Wind and waves course direction 90°
5	1	2	3	4
10	4	10	13	15
15	11	26	32	35
20	19	47	61	65
25	30	77	102	115
30	46	120	157	170

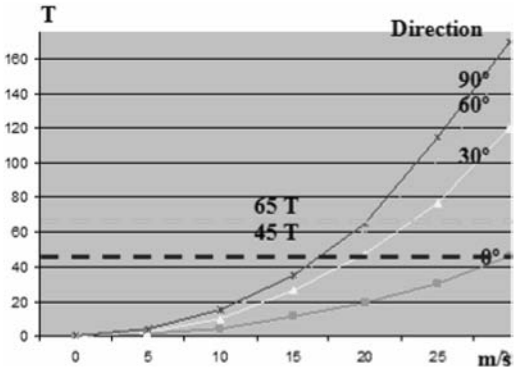

Figure 2. Wind and waves forces on the loaded Suez Max tanker depends on wind velocity and waves accordantly (wind and waves directions are the same).

no limitations, 45 T bollard pull tug has limitations for the FSU or tanker in ballast: wind up to 18 m/s, waves up to 3,5 m.

In case of FSU or tanker breakout (break towage-mooring rope) between SPM and FSU or FSU and tanker, in case of bad weather, wind, waves and current start push FSU or tanker in acting forces direction and if this direction oriented to navigational obstacles, just very fast and correct actions must be taken to solve the problem. Tugs possibilities in case of loaded FSU or tanker are shown on fig. 2 (green line for 65 T bollard pull tug and blue line for tug 45 T bollard pull tug).

4 REQUEST FOR NAVIGATIONAL REGION RECEIVED BY CALCULATIONS AND SIMULATOR TESTINGS

Request for navigational region for the tankers maneuvering after breakout mooring rope in case tanker reach some drift speed received by theoretical calculations were checked by simulator and real data from SPM accident situations. All results were received very similar.

Simulations were made on visual simulator with possibility to simulate ship, tugs and sailing conditions. Simulations made for the emergency conditions, in case, when mooring rope has broken and tanker reached drift speed up to 4 knots before starting towage operation by tug. Simulations results for the loaded tanker drifting in first stage before tug started towage at the speed about 4 knots, presented on figure 3 by 65 T bollard pull tug and for the loaded tanker by 45 T bollard pull tug simulation results in the same conditions are shown on figure 4 and towage parameters for 45 T bollard pull tad are shown on figure 5.

Calculation and simulation results were checked with available experimental (real) results in Butinge terminal (Lithuania), Petrol Baltic SPM (in Baltic Sea) and in other places in which used SPM. Correlation between calculation, simulation and experimental

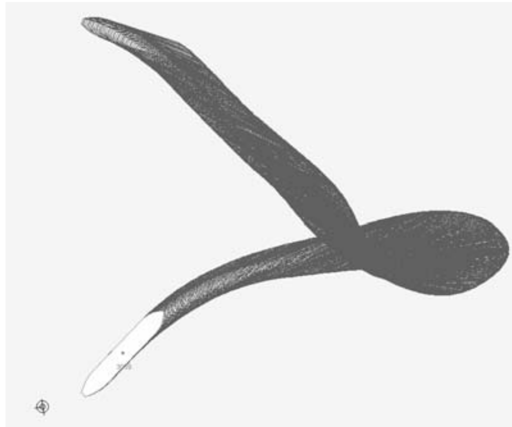

Figure 3. Loaded tanker and 65 T bollard pull tug way for the stopping and later towage tanker (before towage tanker drift speed reached 4 knots): wind 20 m/s; waves 4 m, current 0,5 knots in to the same direction (to E).

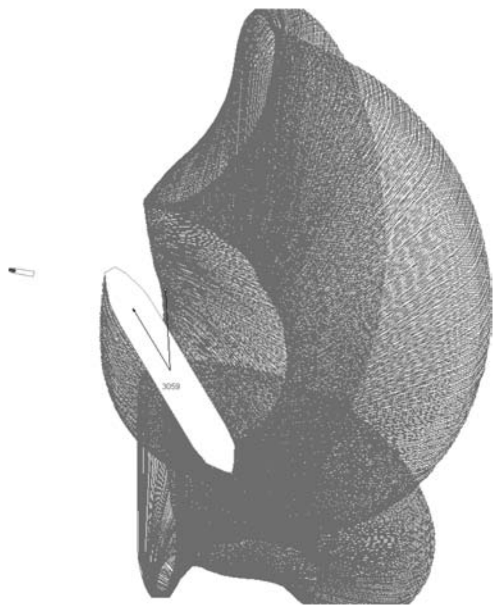

Figure 4. Loaded tanker and 45 T bollard pull tug way for the stopping and later towage tanker, on first tanker drift speed 1,5 knots: wind 20 m/s; waves 4 m, current 0,5 knots in to the same direction (to E).

results are very good and it has shown that calculation methodology, prepared by author and explained in this paper, can be used on first stage for the forecasting situation to use SPM, request for navigational region, minimal tug's bollard pull and other details.

5 CONCLUSIONS

1 Methodology, presented in this paper can be used for the SPM conditions evaluation and forecasting

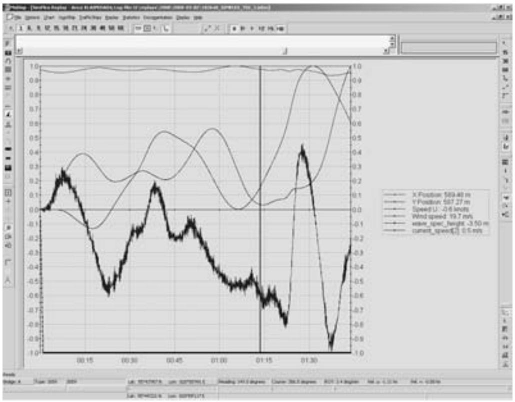

Figure 5. Loaded tanker and tug movement parameters: Time 00.00 – speed 1,5 knots; Tanker stopped by 45 T bollard pull tug and keep practically in the same place; Towage speed at the end of the process reaches 0,3 kn.

requests for navigational region, tugs bollard pull, depends on tankers or FSU parameters.

2 Combination of the calculation methods, simulation possibilities on navigational simulators and checking by real data, could be the main way for receiving good quality results and for preparation of SPM work and emergency procedures.

3 In case of failure FSU or tanker engine or rudder system, strong enough tugs can take precautions measures in advance, stopping on navigational region tanker drifting or FSU and towage away from navigational dangerous places.

4 Theoretical methods are very important during planning of SPM and navigational regions around SPM, selection of the main elements in the region, such as minimal tug bollard pull, tugs maneuverability, ways in different conditions for the towage tanker or FSU away from navigational dangerous regions.

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8.2
Identification of ship maneuvering model using extended Kalman filters

C. Shi, D. Zhao, J. Peng & C. Shen
Merchant Marine College, Shanghai Maritime University, Shanghai, China

ABSTRACT: Ship maneuvering models are the keys to the research of ship maneuverability, design of ship motion control system and development of ship handling simulators. For various frames of ship maneuvering models, determining the parameters of the models is always a tedious task. System identification theory can be used to establish system mathematical models by the system's input data and output data. In this paper, based on the analysis of ship hydrodynamics, a nonlinear model frame of ship maneuvering is established. System identification theory is employed to estimate the parameters of the model. An algorithm based on the extended Kalman filter theory is proposed to calculate the parameters. In order to gain the system's input and output data, which is necessary for the parameters identification experiment, turning circle tests and Zig-zag tests are performed on shiphandling simulator and the initial data is collected. Based on the Fixed Interval Kalman Smoothing algorithm, a pre-processing algorithm is proposed to process the raw data of the tests. With this algorithm, the errors introduced during the measurement process are eliminated. Parameters identification experiments are designed to estimate the model parameters, and the ship maneuvering model parameters estimation algorithm is extended to modify the parameters being estimated. Then the model parameters and the ship maneuvering model are determined. Simulation validation was carried out to simulate the ship maneuverability. Comparisons have been made to the simulated data and measured data. The results show that the ship maneuvering model determined by our approach can seasonably reflect the actual motion of ship, and the parameter estimation procedure and algorithms are effective.

1 INTRODUCTION

Ship maneuvering models are the keys to the research of ship maneuverability, design of ship motion control system and development of ship handling simulators (Shi et al 2006). For various frames of ship maneuvering models, determining the parameters of the models is always a tedious task. The usual approach to determine the ship model parameters is the ship model test. Ship model test is a reliable and accurate method for this purpose. The test is, however, expensive and time-consuming, and usually dependent on some specific model frame, which limits the application of the valuable data (Li 1999). System identification theory can be used to establish system mathematical models by the system's input data and output data. And it has been effectively used in the fields of space technology (Lacy et al 2005), robotic engineering and underwater engineering (Liu et al 2002). Various methodologies have been employed for system identification tasks, which include neural network (Narendra & Parthasarathy 1990), wavelet analysis (Shi et al 2005), and genetic algorithm (Nyarko & Scitovski 2004). Most of the methodologies prove quite effective with the linear system identification.

To most applications, the linear ship maneuvering models present limitations because of lack of accuracy. The Kalman filter is an efficient recursive filter that estimates the state of a dynamic system from a series of noisy measurements (Kalman 1960). It is able to provide solutions to what probably are the most fundamental problems in control theory. The extended Kalman filter (EKF) is the nonlinear version of the Kalman filter and is often considered the *de facto* standard in the theory of nonlinear state estimation (Leondes et al 1970). EKF is widely used in areas of state estimation, object tracking and navigation (Beides & Heydt 1991, Farina et al 2002).

Base on EKF and augmented state equation, this paper intended to tackle identification of non-linear ship maneuvering models.

2 EQUATIONS OF SHIP HORIZONTAL MOTION

Two coordinates are set for the description of ship's horizontal motion, as shown in Figure 1. $E-\xi-\eta$ is the space coordinate, and the plane $E\xi\eta$ lies on the water plane. $O-x-y$ is the ship coordinate. Plane Oxy is parallel to $E\xi\eta$. The origin of the coordinate, O,

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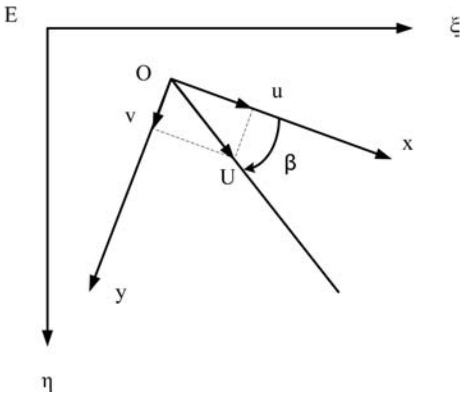

Figure 1. Ship's horizontal motion coordinates.

is attached on the ship's center of gravity. It is so oriented that Ox is aligned with ship's fore and aft line with forward as positive direction, and Oy is aligned abeam and with starboard side as positive direction. Let U be ship's velocity, and β be the drift angle.

Then the motion equations of ship on water surface can be established as,

$$\begin{aligned} \dot{x}(t) &= f(x(t), s(t), t) + w(t) \\ y(t) &= Hx(t) + e(t) \end{aligned} \tag{1}$$

Where $\boldsymbol{x}(t) = [u(t) \quad v(t) \quad r(t)]^{\mathrm{T}}$, $\boldsymbol{s}(t) = [\delta(t) \quad n(t)]^{\mathrm{T}}$, $\boldsymbol{H} = \boldsymbol{I}_{3\times3}$, $f = [f_1 \; f_2 \; f_3]^{\mathrm{T}}$. And u denotes ship's longitudinal velocity, v, the lateral velocity, r, the turning rate of ship's heading, δ, the rudder angle and n, the propeller RPM.

Based on the standard state of the straight motion of ship with constant speed along x axis, the functions $\boldsymbol{f}$ in Equation 1 can be expanded into Taylor series. Compromising the accuracy of the modes and the complexity of the computation of parameter identification, only are the second and lower order series preserved. Further assumptions are made that the ship is symmetrical with x axis and nearly symmetrical with y axis, and that the origin of the coordinate of ship motion is on the gravity center of the ship. With these assumptions, some of the partial derivatives in the Taylor series would be zeros and the equations can be further simplified. Because the longitudinal resistance is proportional to u^2, the zero order, the first order and the second order items of u can be combined and represented as $a_1 u(t)^2$ (Li 1999). Then we have,

$$\begin{aligned} f_1 &= a_1 u(t)^2 + a_2 v(t)^2 + a_3 r(t)^2 + a_4 \delta(t)^2 + a_5 v(t) r(t) \\ &\quad + a_6 v(t)\delta(t) + a_7 r(t)\delta(t) + a_8 u(t) n(t) + a_9 n(t)^2 \\ f_2 &= b_1 v(t) + b_2 r(t) + b_3 \delta(t) + b_4 u(t) r(t) \\ f_3 &= c_1 v(t) + c_2 r(t) + c_3 \delta(t) \end{aligned} \tag{2}$$

Where $a_i(i = 1, 2, \ldots, 9), b_i(i = 1, 2, 3, 4), c_i(i = 1, 2, 3)$ are the parameters of the model. The identification task is to determine these parameters.

3 CALCULATION OF MODEL PARAMETERS USING EKF

In order to identify the parameters, a_i, b_i and c_i, of ship maneuvering model, the extended Kalman filter (EKF) algorithm is employed. The parameters of the model are also taken as the state variables and then the augmented state space contains the model parameters as well as the original state variables. Hence, the augmented state equation can be established. Our algorithm of parameter identification is based on the EKF method and the augmented state equation.

Take the parameters, a_i, b_i and c_i, in Equation 2 as state variables and expand Equation 1, then the augmented state equation and the observation equation are established as,

$$\begin{aligned} \dot{\boldsymbol{x}}^a(t) &= \boldsymbol{f}^a(\boldsymbol{x}^a(t), \boldsymbol{s}(t), t) + \boldsymbol{w}(t) \\ \boldsymbol{y}(t) &= \boldsymbol{H}\boldsymbol{x}^a(t) + \boldsymbol{e}(t) \end{aligned} \tag{3}$$

where

$$\boldsymbol{x}^a(t) = \begin{bmatrix} u(t) & v(t) & r(t) & a_i(t) & b_i(t) & c_i(t) \end{bmatrix}^{\mathrm{T}}_{1\times19},$$

$$\boldsymbol{H} = \begin{bmatrix} 1 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 1 & 0 & \cdots & 0 \end{bmatrix}_{3\times19}$$

Equation 3 can be discretized and transformed into the following discrete non-linear state function,

$$\begin{aligned} \boldsymbol{x}^a(k+1) &= \boldsymbol{f}^a(\boldsymbol{x}^a(k), \boldsymbol{s}_m(k), k) + \boldsymbol{\omega}(k) \\ \boldsymbol{y}(k) &= \boldsymbol{H}\boldsymbol{x}^a(k) + \boldsymbol{e}(k) \end{aligned} \tag{4}$$

Where $\boldsymbol{s}_m(k)$ denotes the average value of sampled values of inputs at $T(k)$ and $T(k+1)$. T is the sampling period. $\boldsymbol{\omega}(k)$ and $\boldsymbol{e}(k)$ are white noise series with variances of $\boldsymbol{Q}$ and $\boldsymbol{R}$, respectively. And,

$$\boldsymbol{f}^a = \begin{bmatrix} f_1^a & f_2^a & \cdots & f_{19}^a \end{bmatrix}^{\mathrm{T}}.$$

Where,

$$\begin{aligned} f_1^a &= u(k) + Ta_1(k)u(k)^2 + Ta_2(k)v(k)^2 + Ta_3(k)r(k)^2 \\ &\quad + Ta_4(k)\delta_m(k)^2 + Ta_5(k)v(k)r(k) + Ta_6(k)v(k)\delta_m(k) \\ &\quad + Ta_7(k)r(k)\delta_m(k) + Ta_8(k)u(k)n_m(k) + Ta_9(k)n_m(k)^2 \\ f_2^a &= v(k) + Tb_1(k)v(k) + Tb_2(k)r(k) + Tb_3(k)\delta_m(k) + \\ &\quad Tb_4(k)u(k)r(k) \\ f_3^a &= r(k) + Tc_1(k)v(k) + Tc_2(k)r(k) + Tc_3(k)\delta_m(k) \\ f_4^a &= a_1(k) \\ &\vdots \\ f_{19}^a &= c_3(k) \end{aligned}$$

By Equation 4, we have the following EKF recursive equations,

$$\begin{aligned} \hat{\boldsymbol{x}}^a(k+1|k) &= \boldsymbol{f}^a(\hat{\boldsymbol{x}}^a(k), \boldsymbol{s}_m(k), k) \\ \boldsymbol{P}(k+1|k) &= \boldsymbol{\Phi}\boldsymbol{P}(k)\boldsymbol{\Phi}^{\mathrm{T}} + \boldsymbol{Q} \\ \boldsymbol{K}(k+1) &= \boldsymbol{P}(k+1|k)\boldsymbol{H}^{\mathrm{T}}[\boldsymbol{H}\boldsymbol{P}(k+1|k)\boldsymbol{H}^{\mathrm{T}} + \boldsymbol{R}]^{-1} \\ \boldsymbol{P}(k+1) &= [\boldsymbol{I} - \boldsymbol{K}(k+1)\boldsymbol{H}]\boldsymbol{P}(k+1|k) \\ \hat{\boldsymbol{x}}^a(k+1) &= \hat{\boldsymbol{x}}^a(k+1|k) + \boldsymbol{K}(k+1)[\boldsymbol{y}(k+1) - \boldsymbol{H}\hat{\boldsymbol{x}}^a(k+1|k)] \end{aligned} \tag{5}$$

Where:

$$\boldsymbol{\Phi} = \left.\frac{\partial \boldsymbol{f}^a}{\partial \boldsymbol{x}^a}\right|_{\boldsymbol{x}^a = \hat{\boldsymbol{x}}^a(k)}$$

By the recursive Equation 5, the filtered vector, $\hat{\boldsymbol{x}}^a(k)$, of the augmented state equation (Equ. 4) can be calculated. Thereby the estimated model parameters, a_i, b_i and c_i, are determined. And hence the ship maneuvering model can be established.

4 IDENTIFICATION PROCEDURES AND VALIDATION ANALYSIS

Shiphandling simulator is used to perform the identification experiment. There are several advantages by using the data retrieved from the shiphandling simulators for the identification purpose. Firstly, simulators can provide the data of ship motion without interference of external factors such as the effect of wind and current. Secondly, accurate ship parameters and maneuvering characteristic are provided. And thirdly, ideal environmental conditions, e.g., uniform water depth, can be set with the operational areas.

4.1 *Data preprocessing*

To get the raw data, Zig-zag test is performed with a shiphandling simulator. The data are recorded with sampling period $T = 2$s. The recorded data are: ship position, s_ξ, s_η, in space coordinate, ship's heading ϕ, rudder angle δ and propeller RPM n. Other data needed, such as ship's longitudinal speed u, lateral speed v, and rate of turn r, can be deduced from the recorded data.

Let s_ξ be the displacement of ship position on $E\xi$, and u_ξ, a_ξ be the speed and acceleration respectively, which can be calculated using s_ξ. The ship motion along $E\xi$ can be described by the following state equation and observation equation,

$$\begin{aligned} \boldsymbol{X}(k+1) &= \boldsymbol{\Phi}\boldsymbol{X}(k) + \boldsymbol{\omega}(k) \\ \boldsymbol{Z}(k) &= \boldsymbol{H}(k)\boldsymbol{X}(k) + \boldsymbol{n}(k) \end{aligned} \quad (6)$$

Where,

$$\boldsymbol{X}(k) = \begin{bmatrix} s_\xi(k) & u_\xi(k) & a_\xi(k) \end{bmatrix}^{\mathrm{T}},$$

$$\boldsymbol{\Phi} = \begin{bmatrix} 1 & T & \frac{T^2}{2} \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix},$$

$$\boldsymbol{H} = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix},$$

$$\boldsymbol{Z}(k) = \begin{bmatrix} s_\xi(k) \end{bmatrix}.$$

And $\boldsymbol{\omega}(k)$ is the white noise series with zero mean and variance $\boldsymbol{Q}$,

$$\boldsymbol{Q} = 2\alpha\sigma_a^2 \begin{bmatrix} \frac{1}{20}T^5 & \frac{1}{8}T^4 & \frac{1}{6}T^3 \\ \frac{1}{8}T^4 & \frac{1}{3}T^3 & \frac{1}{2}T^2 \\ \frac{1}{6}T^3 & \frac{1}{2}T^2 & T \end{bmatrix}$$

$\boldsymbol{n}(k)$ is the white noise series with zero mean and variance σ_R^2, a_ξ is the acceleration of the ship motion along $E\xi$, and σ_a^2 is its variance. α is the operation parameter and T is the sampling period ($T = 2$s). By Equation 6, we have the following recursive equations of Kalman filter.

$$\begin{aligned} \hat{\boldsymbol{X}}(k+1|k) &= \boldsymbol{\Phi}\hat{\boldsymbol{X}}(k) \\ \boldsymbol{P}(k+1|k) &= \boldsymbol{\Phi}\boldsymbol{P}(k)\boldsymbol{\Phi}^{\mathrm{T}} + \boldsymbol{Q}(k) \\ \boldsymbol{K}(k+1) &= \boldsymbol{P}(k+1|k)\boldsymbol{H}^{\mathrm{T}}[\boldsymbol{H}\boldsymbol{P}(k+1|k)\boldsymbol{H}^{\mathrm{T}} + \sigma_R^2\boldsymbol{I}]^{-1} \\ \boldsymbol{P}(k+1) &= [\boldsymbol{I} - \boldsymbol{K}(k+1)\boldsymbol{H}]\boldsymbol{P}(k+1|k) \\ \hat{\boldsymbol{X}}(k+1) &= \hat{\boldsymbol{X}}(k+1|k) + \boldsymbol{K}(k+1)[\boldsymbol{Z}(k+1) - \boldsymbol{H}\hat{\boldsymbol{X}}(k+1|k)] \end{aligned} \quad (7)$$

and the smoothing equations for fixed intervals,

$$\begin{aligned} \hat{\boldsymbol{x}}(k|N) &= \hat{\boldsymbol{x}}(k) + \boldsymbol{A}_s(k)[\hat{\boldsymbol{x}}(k+1|N) - \boldsymbol{\Phi}\hat{\boldsymbol{x}}(k)] \\ \boldsymbol{A}_s(k) &= \boldsymbol{P}(k)\boldsymbol{\Phi}^{\mathrm{T}}\boldsymbol{P}^{-1}(k+1|k) \end{aligned} \quad (8)$$

The initial conditions for the recursive Kalman filter are,

$$\hat{\boldsymbol{X}}(2) = \begin{bmatrix} Z(2) & \frac{Z(2)-Z(1)}{T} & 0 \end{bmatrix},$$

$$\boldsymbol{P}(2) = \begin{bmatrix} \sigma_R^2 & \frac{\sigma_R^2}{T} & 0 \\ \frac{\sigma_R^2}{T} & \frac{2\sigma_R^2}{T^2} & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

And the initial condition for fixed interval smoothing is,

$$\hat{\boldsymbol{X}}(N|N) = \hat{\boldsymbol{X}}(N)$$

By the optimal smoothed vector $\hat{\boldsymbol{x}}(k|N)$, the ship's velocity along the $E\xi$ axis, u_ξ, can be calculated.

With similar approaches, the ship's velocity u_η along the $E\eta$ axis can be calculated from the displacement, s_η, on the $E\eta$ axis. The rate of turn, r, can be calculated using ship's heading, ϕ.

The ship's motion speed is,

$$U = \sqrt{u_\xi{}^2 + u_\eta{}^2},$$

And the course made good is,

$$\varphi = \arctan\left(\frac{u_\xi}{u_\eta}\right).$$

And then ship's longitudinal and lateral velocities are,

$$\begin{aligned} u &= \cos\beta, \\ v &= \sin\beta. \end{aligned} \quad (9)$$

Where β is the drifting angle, $\beta = \varphi - \phi$.

By the preprocessing of the raw data of ship maneuvering tests, we get the smoothed data, δ, n, u, v and r, which can be used for model parameter identification. Figures 2 and 3 illustrate the rate of turn calculated from the raw data and the smooth result, respectively.

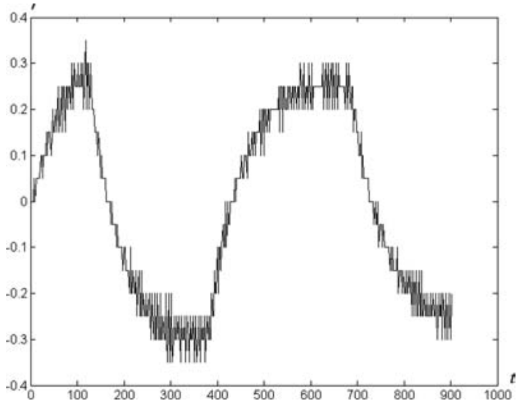

Figure 2. Rate of turn calculated from raw data.

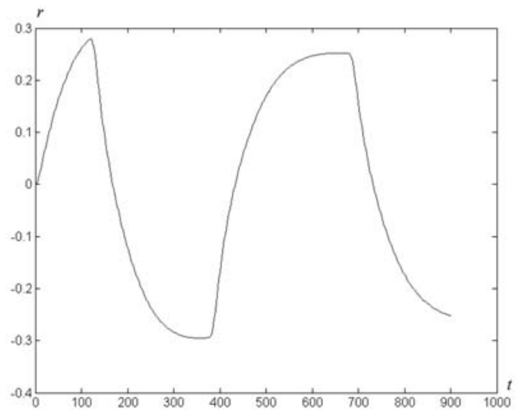

Figure 3. Smoothed rate of turn.

Table 1. Result of parameter identification.

Param	Value	Param	Value
a_1	1.4347×10^{-4}	a_2	-5.4857×10^{-1}
a_3	-5.0703×10^{-2}	a_4	-7.8174×10^{-6}
a_5	-2.4131×10^{-1}	a_6	2.0968×10^{-4}
a_7	1.7521×10^{-4}	a_8	-3.8163×10^{-5}
a_9	3.8536×10^{-6}	b_1	-1.7511×10^{-1}
b_2	3.3215×10^{-2}	b_3	-2.1508×10^{-4}
b_4	-3.125×10^{-2}	c_1	-1.8988×10^{-2}
c_2	-2.2555×10^{-2}	c_3	1.9627×10^{-4}

4.2 *Parameter identification*

With the augmented state space, the model parameters in the discrete state equation, Equation 4, are identified. In our experiment, the initial conditions for recursive Equation 5 are set as,

$\boldsymbol{P}(0) = \alpha \boldsymbol{I}$, where $\alpha = 10^5$ and $\boldsymbol{I}$, 19×19 identical matrix

$$\hat{\boldsymbol{x}}^a(0) = \begin{bmatrix} u(0) & v(0) & r(0) & 0 & \cdots & 0 \end{bmatrix}^{\mathrm{T}}$$

Table 1 shows the result of the identification.

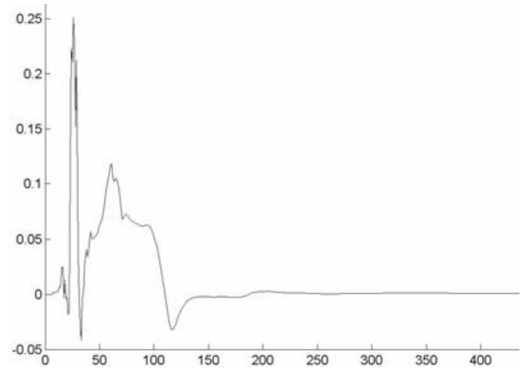

Figure 4. Convergence of the parameters a_1.

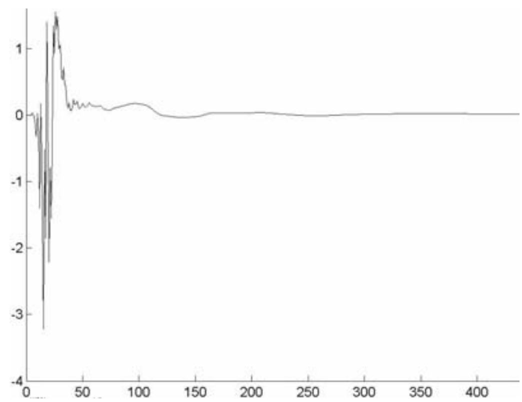

Figure 5. Convergence of the parameters b_2.

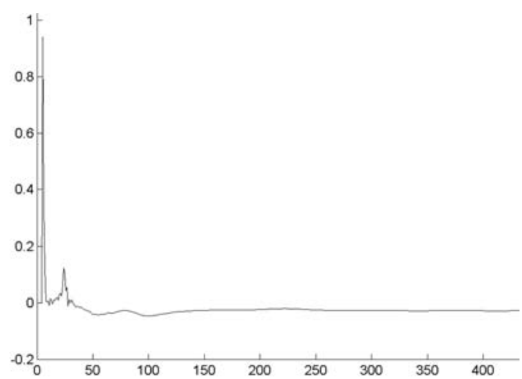

Figure 6. Convergence of the parameters c_1.

4.3 *Convergence and verification of the parameters*

In the experiment, the parameters converged quite well after 200 recursive steps. The convergence status of some of the parameters are shown in Figures 4–6.

Using the identified parameters, a_i, b_i, c_i, the nonlinear maneuvering model of the target ship can be established. We verify the identified model by performing standard maneuvering tests such as turning

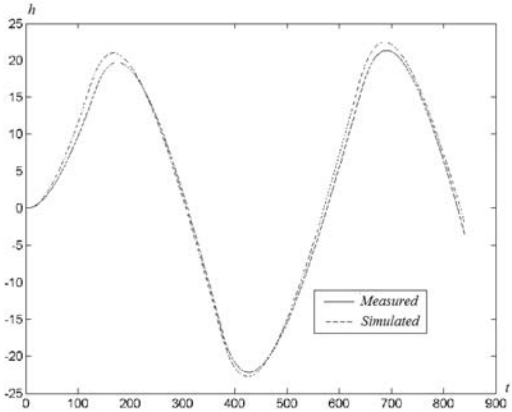

Figure 7. Heading comparison in 20/20 Zig-zag test.

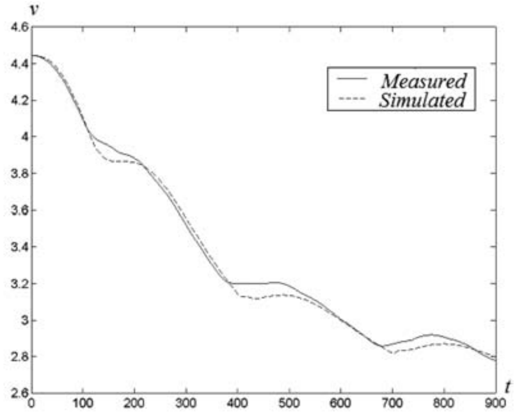

Figure 8. Speed comparison in 20/20 Zig-zag test.

circle test, spiral test, zig-zag test, etc., and compare the results. Figure 3 shows the comparison of the ship's headings of zig-zag tests of the identified model and the target ship. Figure 3 is the speed comparison. The comparison of the turning circle tests is illustrated in Figure 4, together with the errors of its elements listed in Table 2. From these results it can be seen that the model output agrees quite well with that of the target ship. Simulation tests show that the ship maneuvering model established by our approach can represent the ship maneuvering with reasonable accuracy.

5 CONCLUSIONS

Based on the analysis of ship hydrodynamics, a nonlinear model frame of ship maneuvering is established. System identification theory is employed to estimate the parameters of the model. An algorithm based on the extended Kalman filter theory is proposed to calculate the parameters. In order to get data samples for the parameters identification experiment, turning circle tests and Zig-zag tests are performed on shiphandling simulator and the raw data is collected. Based on the Fixed Interval Kalman Smoothing algorithm, a preprocessing algorithm is proposed to process the raw data of the tests. With this algorithm, the errors introduced during the measurement process are eliminated. Parameters identification experiments are designed to estimate the model parameters, and the ship maneuvering model parameters estimation algorithm is extended to modify the parameters being estimated. Then the model parameters and the ship maneuvering model are determined. Simulation validation was carried out to simulate the ship maneuverability. Comparisons have been made to the simulated data and measured data. The results show that the ship maneuvering model determined by our approach can reasonably reflect the actual motion of ships, and the parameter estimation procedure and algorithms are effective.

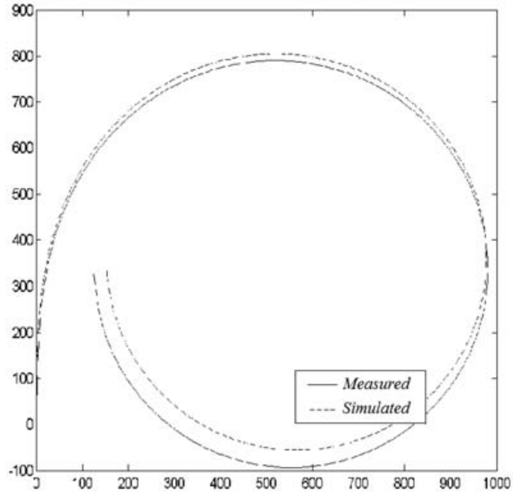

Figure 9. Turning circle comparison.

Table 2. Errors with turning circle test.

Items	Measured	Simulated	Error(%)
Advance	790.0	805.0	1.90
Transfer	500.0	525.0	5.00
Diameter	980.0	978.0	−0.20

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8.3
Estimating manoeuvres safety level of the Unity Line m/f "Polonia" ferry at the port of Ystad

A. Kowalski
Unity Line Ltd., Szczecin, Poland

ABSTRACT: Briefly characteristic of m/f "Polonia" ferry has been presented. For the port of Ystad, topographical, hydro and meteorological conditions have been described. Moorings of the "Polonia" ferry at the port of Ystad have been discussed. Researches based on experts' questionnaire and statistical methods of analyses have been exemplified. Finally there are some conclusions concerning improvements of ferries manoeuvres safety.

1 INTRODUCTION

Estimating moorings manoeuvres safety level is a basic problem undertaken in the procedure of manoeuvre planning. Captain or Pilot manoeuvring the vessel needs to take into consideration the vertical and horizontal restrictions of the navigating area. During vessel manoeuvre process it is necessary to take also into consideration other important factors such as hydro meteorological conditions, equipment and standard of technical maintenance of the vessel, deck and engine crew qualifications, the condition of navigational aids of the navigational area, the intensity of vessel traffic and the quality of local Vessel Traffic Service.

Researches evaluating the level of safety moorings manoeuvres of the m/f "Polonia" ferry at the port of Ystad based on experts' questionnaire have been carried out. Researches of manoeuvres only one vessel, verified during more than 10 years of experience, at only one port give the chance to reject influence of factors others than selected in hypothetical questionnaire. Researches were conducted for the following variables: force and direction of wind, visibility, day and night manoeuvres. Additional variable has been introduced: manoeuvres done with or without Ferry Nautical Anti-collision System (FNAS) – specialized equipment type of Electronic Nautical Chart. Experts asked in questionnaire were captains with manoeuvring experience of m/f "Polonia". Every one of them was a holder of suitable pilot exemption certificate. 16 experts completed and returned the questionnaire.

Figure 1. View of m/f "Polonia".

2 OBJECT AND PLACE OF RESEARCHES

Unity Line m/f "Polonia" ferry was built in 1995 at Norwegian Shipyard Langsten Slip & Batbyggeri A/S in Tomfjord. She is modern passenger rail car ferry, especially designed for Świnoujscie – Ystad service. The ferry is berthed at Ystad's rail ferry Stand no 4. Below are some technical and manoeuvre data of m/f "Polonia":

over all length 169,9 m, breadth 28 m, GRT 29875;
4 main engines Stork-Wartsila type each 3960, kW clutched in twos, each pair drive one of two controllable pitch propeller;
behind each of propeller double, Becker type flap rudder is situated;
3 bow thrusters, 1 stern thruster, each 1600 kW Brunwoll SPA-VP type;
summer draft 6,2 m corresponding to wind pressure area 3250 m^2;
4 navigational radars, first radar aerial is situated on the bow, second on stern, last two are on radar mast above wheelhouse.

M/f "Polonia" is equipped with Ferry Nautical Anti-collision System (FNAS). FNAS is a kind of Electronic Nautical Chart (ENC) with some function specially designed for pilot's passages and manoeuvres.

On the bridge in a centre, main ferry controls are located. M/f "Polonia" always berths port side for this reason on bridge port wing additional ferry steering and manoeuvring control equipment are located. Main controls are joysticks of both controllable pitch propellers, coupled in one joystick which control three bow thrusters, another one for stern thruster, hand wheels for each main rudders with possibility of synchronized operation. On steering console FNAS LCD monitor is mounted. Above it is the monitor of ship's internal TV system with a selected view of ferry area.

Port of Ystad is located on the southern Baltic coast of Sweden. Due to its location the port is well sheltered from northerly winds, but is fully exposed to winds

Figure 2. View of m/f "Polonia" manoeuvring controls on port side wing.

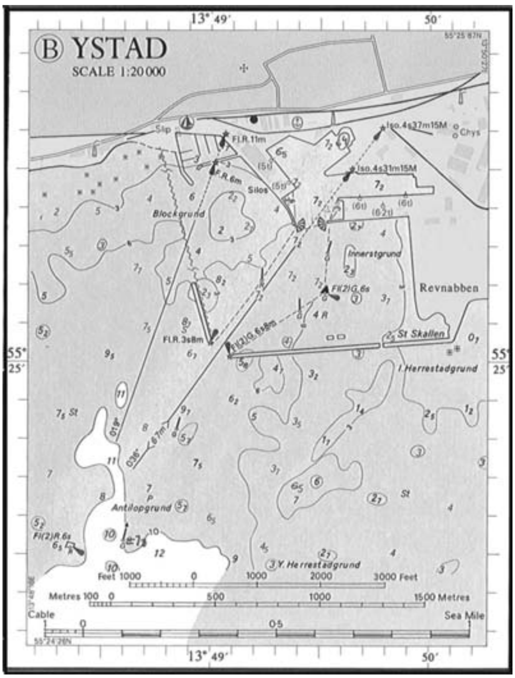


Figure 3. Nautical chart of Ystad and approaches.
[BA Chart, UKHO].

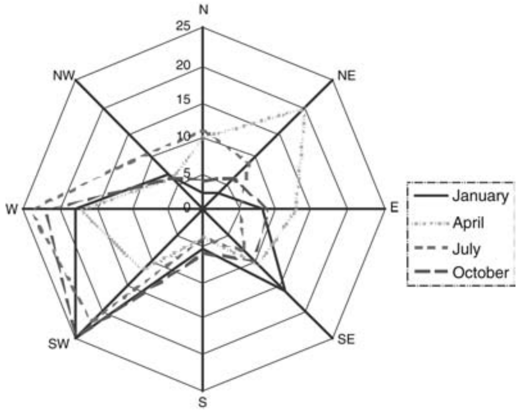


Figure 4. Mean values of wind occurrence form given directions for each quarter of year.
[data UKHO, BSH].

from southern directions. Force of easterly winds is only a little reduced due to port location on south-eastern cape. Ystad port is relatively well secured from westerly winds. The inner port area has additional protection from west by high grain silos and port's buildings along the western quay – Vastra Kajen.

M/f "Polonia" was designed as maximum size ferry for berthing at rail stand no 4. Then for summer draft 6,2 m, the ferry has only 0,5 m draft reserve. At the port water level is changing according to the same rules as all south-western Baltic. When strong wind is blowing from southern and south-western directions, water level is rapidly falling down to 1 meter below mean water level. In this hydro and meteorological conditions during powerful manoeuvres of own propellers and thrusters the shallow water effect is of great importance.

3 MANOEUVRING OF THE FERRY M/F "POLONIA " IN YSTAD

During multi year operation of the ferry, methods of manoeuvres were standardized and optimized. Since the ferry was properly designed for the Świnoujscie – Ystad line, for the changed hydro and meteorological conditions manoeuvring strategy will not be changed. Only some adjustments of settings for propellers and thrusters will be necessary.

Based on captain's experience, some stages of manoeuvres of m/f "Polonia" at Ystad were separated. Criteria of manoeuvres division was the goal done on each separate stage. 8 stages for entry manoeuvres and 5 for departure were obtained. The table on figures 5.1 and 5.2 show manoeuvres division placed at expert's questionnaire including events discriminating the stages.

Scale of difficulty and complication of manoeuvres can easily estimate based on the ferry speed on each stage of mooring. When passing the outer heads (110 m distance between heads) speed is about 10,5 kts, in the inner heads about 7 kts. At the beginning of slow down at the moment of reversing the engine speed is about 5,5 kts and at this speed on a distance of 130 m, the ferry stops and continues left side turning. In very good hydro meteorological conditions at wind force 0 m/s, the ferry passes concrete elements of ports infrastructure on the distance of 20–25 m. The distances to piers and breakwaters are reduced rapidly simultaneously with the deterioration of hydro meteorological conditions.

No	Consecutive stages of ferry entering manoeuvres	Events discriminating the stages
		Sea buoy Ystad
1	Approaches to the port	Stabilized in the line of leading lights
2	Outer port entry after passing heads.	Red pole beam
3	Deviation on the left side of leading lights.	Left inner head on fore beam
4	Turning to the left	Quay corner left beam
5	Continuation of turning, commencing of stopping the forward run	Longitudinal run stopped, stern passed quay IV corner
6	Continuation of turning, commencing of astern run	Completing of astern run
7	Approaching to the quay	Ferry contact with fender at the Quay
8	Astern run alongside	Ferry alongside at the train stand

Figure 5.1. Examples of expert's entering questionnaire.

No	Consecutive stages of ferry departure manoeuvres	Events discriminating the stages
		Ferry alongside at the train stand
1	Unberthing, commencing the run forward	Abeam quay corner I/IV
2	Turning to the port	Turning stopped
3	Turning to starboard	Ferry in the line of leading lights
4	Inner port passage	Ferry passed breakwater heads
5	Departure the harbour	Sea buoy

Figure 5.2. Examples of expert's departure questionnaire.

4 EXPERT RESEARCHES OF MOORING SAFETY

Researches were based on anonymous questionnaire revered directly to respondents. Every respondent received 12 sheets with relevant questions. Each questionnaire consists of entering or departure manoeuvres tables, same as on figures 5.1 and 5.2 with place for individual answer for every stage of manoeuvres and for changeable conditions of manoeuvres.

Scale of opinion was integer number started from 1 for very easy manoeuvre to 10 for very risky manoeuvre but still feasible with acceptable level of risk. If the level of risk exceeded acceptable level experts were asked to use mark "X" instead of integer number. Initial conditions were: day, no wind, good visibility and manoeuvres done without support of FNAS. Next the opinion concerning the following conditions was estimated:

night manoeuvres;
visibility 0,2 Nm and 50 m;
wind E 5 m/s, E 15 m/s, E 25 m/s;
wind W 5 m/s, W 15 m/s, W 25 m/s;
wind S 5 m/s, S 15 m/s, S 25 m/s;
manoeuvres done with support of FNAS.

Minimized to 3 levels only the wind and visibility variable were taken into consideration. Recognized that additional levels will generate non-sharp and subjective component to opinions. 4 Nm suggest good visibility. 0,2 Nm mean bad visibility – only the nearest area around the ferry is visible, navigational marks and aids are not visible. Very bad visibility 50 m – possible only a view of the water below conning position. Stern and amidships are not visible. Earlier researches reveal that critical force of the wind for m/f "Polonia" ferry is 27 m/s. For this reason the following has been assumed: weak wind force as 5 m/s, strong wind 15 m/s and very strong wind force 25 m/s. 3 directions of the wind has been selected: W, S, E. Choice of this direction respects not only the occurrence of the wind according to fig 4 but also exposed the port area for winds from the selected directions.

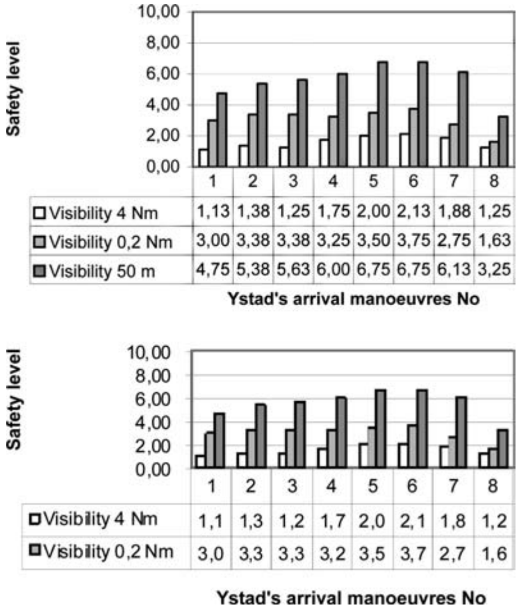
5 ANALYSIS OF SELECTED RESULTS OF RESEARCHES

For all conditions covered by 12 questionnaires, as anticipated, no expert estimated any stage of the manoeuvre "as risk that' will exceed acceptable level". Once again well-calculated critical force of the wind for m/f "Polonia" ferry – 27 m/s was confirmed.

Selected results of researches are shown on figures 6, 7, 8. For each result was calculated range of mean safety level with 0,95 probability and passed test of normality distribution. For each stage of manoeuvres and for each variable difference of average estimate of safety level was tested by t-test pre-test – post-test for a standard significant level 0,05. Acceptance of zero hypothesis means no changes in safety level opinions despite changes of visibility, force and direction of wind, night and daytime, usage of FNAS. Rejection of zero hypothesis means changes in experts' opinion.

5.1 *Entering and departure daytime manoeuvres with restricted visibility. No wind*

For daytime, at no wind conditions, on each stage of manoeuvres with variable described as visibility for every stage, zero hypothesis was rejected. For each stage of manoeuvres, along with decreasing of visibility deterioration of experts' opinions concerning safety level was observed. Approaching manoeuvres



	1	2	3	4	5	6	7	8
Visibility 4 Nm	1,13	1,38	1,25	1,75	2,00	2,13	1,88	1,25
Visibility 0,2 Nm	3,00	3,38	3,38	3,25	3,50	3,75	2,75	1,63
Visibility 50 m	4,75	5,38	5,63	6,00	6,75	6,75	6,13	3,25

	1	2	3	4	5	6	7	8
Visibility 4 Nm	1,1	1,3	1,2	1,7	2,0	2,1	1,8	1,2
Visibility 0,2 Nm	3,0	3,3	3,3	3,2	3,5	3,7	2,7	1,6

Figure 6. Results of experts' opinions for manoeuvres during restricted visibility without the use of FNAS.

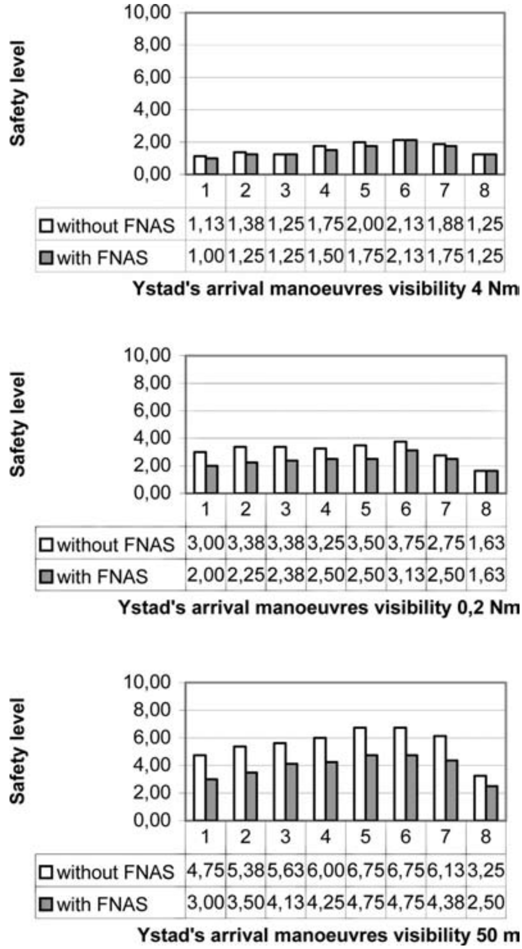
were estimated as less safe than departure from Ystad. Regardless of the kind of manoeuvres at visibility reduced from 4 Nm to 50 m, 3–4 time reduction of estimated safety level was observed. That' means strong influence of restricted visibility on manoeuvres safety.

5.2 *Entering and departure daytime manoeuvres with restricted visibility with FNAS in use. No wind.*

At good visibility of 4 Nm, the average estimate of safety level varies from 1 to 2. Except for entry manoeuvres no 4 and 5, the zero hypothesis was not rejected. For 4th and 5th manoeuvres at these conditions a dozen or so improvement of safety was observed when FNAS was in use. This manoeuvres was estimated as a most difficult. For the best possible hydro meteorological conditions, usage of FNAS can also improve safety of manoeuvres.

For bad visibility of 0,2 Nm for manoeuvres without FNAS, average experts' opinions do not exceed "4". When FNAS was in use at the same visibility conditions, 50 percent in crease in safety was observed. That was observed for all kinds of manoeuvres except entry no 7 and 8 where ferry directly approaches to the quay and keeps contact with fender moves along stand no 4. For these stages sight distance of 0,2 Nm enables sufficient level of visibility for execution of safety manoeuvres.

At very bad visibility up to 50 m, the most difficult stages were estimated up to "7". For all kinds of entering and departure manoeuvres the average safety level was improved about 50 percent when FNAS was



	1	2	3	4	5	6	7	8
without FNAS	1,13	1,38	1,25	1,75	2,00	2,13	1,88	1,25
with FNAS	1,00	1,25	1,25	1,50	1,75	2,13	1,75	1,25

	1	2	3	4	5	6	7	8
without FNAS	3,00	3,38	3,38	3,25	3,50	3,75	2,75	1,63
with FNAS	2,00	2,25	2,38	2,50	2,50	3,13	2,50	1,63

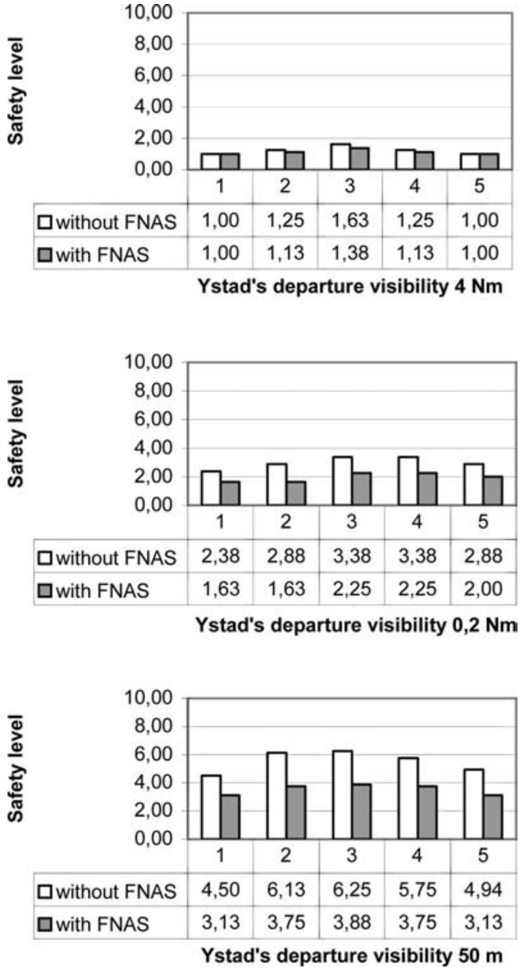
	1	2	3	4	5	6	7	8
without FNAS	4,75	5,38	5,63	6,00	6,75	6,75	6,13	3,25
with FNAS	3,00	3,50	4,13	4,25	4,75	4,75	4,38	2,50

Figure 7.1. Results of experts' opinions on entering manoeuvres in restricted visibility without FNAS compared to manoeuvres with FNAS.

in use. In this circumstances average safety level does not exceed "5".

5.3 *Daytime manoeuvres. Easterly wind. Good visibility*

Average experts safety opinions for easterly wind force 0 m/s – 5 m/s, 5 m/s – 15 m/s, 15 m/s – 25 m/s were compared. For every stage zero hypotheses was rejected except entering manoeuvres no 6 and 8 when compared easterly wind 0 m/s – 5 m/s. During stage no 6 weak easterly wind not disturb manoeuvre. For stage 8 when ferry keeps contact with fenders on quay and moves along stand no 4, the weak opposite wind never disturbs the progress. For all estimated, manoeuvres at easterly wind were described as the least safe. For the most difficult entry stages no 4, 5, 6, 7 sometimes levels "10" appear the last acceptable safety level. But taken this into consideration only for entry manoeuvres stage no 5 average level exceeds "9" at the easterly wind 25 m/s.



	1	2	3	4	5
without FNAS	1,00	1,25	1,63	1,25	1,00
with FNAS	1,00	1,13	1,38	1,13	1,00

Ystad's departure visibility 4 Nm

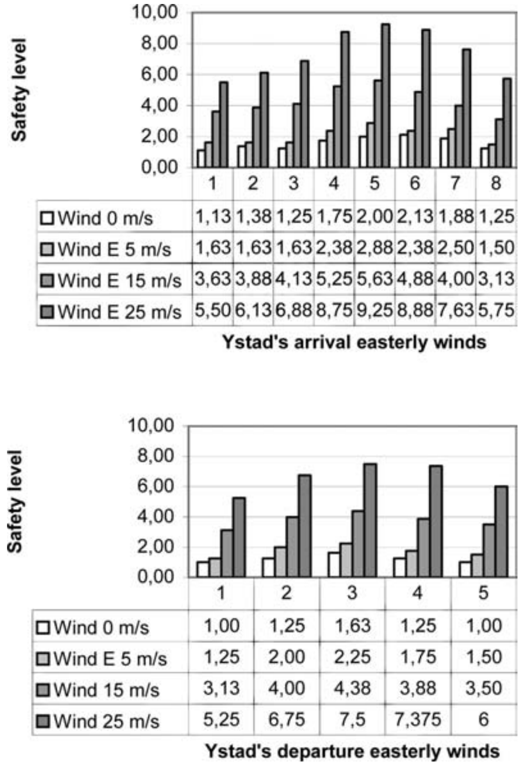
	1	2	3	4	5
without FNAS	2,38	2,88	3,38	3,38	2,88
with FNAS	1,63	1,63	2,25	2,25	2,00

Ystad's departure visibility 0,2 Nm

	1	2	3	4	5
without FNAS	4,50	6,13	6,25	5,75	4,94
with FNAS	3,13	3,75	3,88	3,75	3,13

Ystad's departure visibility 50 m

Figure 7.2. Results of experts' opinions on departure manoeuvres in restricted visibility without FNAS compared to manoeuvres with FNAS.



	1	2	3	4	5	6	7	8
Wind 0 m/s	1,13	1,38	1,25	1,75	2,00	2,13	1,88	1,25
Wind E 5 m/s	1,63	1,63	1,63	2,38	2,88	2,38	2,50	1,50
Wind E 15 m/s	3,63	3,88	4,13	5,25	5,63	4,88	4,00	3,13
Wind E 25 m/s	5,50	6,13	6,88	8,75	9,25	8,88	7,63	5,75

Ystad's arrival easterly winds

	1	2	3	4	5
Wind 0 m/s	1,00	1,25	1,63	1,25	1,00
Wind E 5 m/s	1,25	2,00	2,25	1,75	1,50
Wind 15 m/s	3,13	4,00	4,38	3,88	3,50
Wind 25 m/s	5,25	6,75	7,5	7,375	6

Ystad's departure easterly winds

Figure 8. Results of experts' opinions on maneuvers during easterly winds.

6 CONCLUSIONS

The paper presents selected results of experts' researches based on questionnaire.

By the experts' researches, it is possible to estimate of the mooring manoeuvres safety level. The difference average of safety levels for consecutive manoeuvres confirm the correct division entry manoeuvres for 8 stages, and departure manoeuvres for 5 stages. According to results of researches, the most dangerous manoeuvring conditions are during the 25 m/s wind when safety level appears "10" the last acceptable safety level. For strong winds 15 m/s and during 50 m restricted visibility, experts' opinions are situated at the center of safety scale.

During any kind of restricted visibility when Ferry Nautical Anti-collision System (FNAS) was in use, improvement on safety about 50 percent was observed. Manoeuvres done with support of FNAS always improve safety level. Researches were conducted on the ferries, where persons manoeuvring the vessel have excellent theoretical and practical knowledge about sailing areas. Presumably, when the vessel is manoeuvring on the less known areas, improvement of the safety level should be more effective.

Carrying out the experts' questionnaire researches, it is possible to establish objectively hydro meteorological conditions for selected and satisfied manoeuvres safety level. Researches may be used for risk management at shipping companies. Additionally results of researches may be used for planning ship's operations during extreme hydro and meteorological conditions.

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8.4
Conceptual model of port security simulating complex (Bulgarian Standpoint)

B. Mednikarov & N. Stoyanov
N.Y. Vaptsarov Naval Academy, Varna, Bulgaria

K. Kalinov
G.S. Rakovski Defence and Staff College, Sofia, Bulgaria

ABSTRACT: Using modeling and simulations has established itself as the most effective approach of preparing personnel engaged with crisis management, including the training of port security responsible personnel. On the background of presenting the overall methodology of transforming Bulgarian Harbour Protection System, the paper formulates a set of requirements for port security related education and training and proposes a general model of a simulating complex supporting the education and training process.

1 INTRODUCTION

There is no doubt that modeling and simulations (M&S) has no alternative in the modern education and training (E&T). The port security E&T is not an exception.

The process of elaborating a conceptual model of port security simulating complex in Bulgaria coincides with the process of transforming the Harbour Protection System (HPS). In addition to the concomitant problems, this coincidence causes a positive opportunity – to avoid adjustment of an existing simulating system to a new HPS realization and to elaborate a M&S complex simultaneously with the that is to be modelled.

2 BULGARIAN PORT SECURITY SYSTEM

When elaborating a variant for optimization of the Bulgarian HPS, we took into account two types of considerations.

The first group, named "*scientific considerations*", is a direct result of the theoretical analysis of the security systems as a particular class of organizations and the application of the "*mission approach*" for functional analysis to the Bulgarian MSS performance.

The second group of considerations, named "*an accomplished facts or facts of life*", is a result of studying the Bulgarian MSS current status.

The summary of so called "*scientific considerations*" is:

1. The HPS is to possess greater "informational capacity" than the opposing organizations do.
2. The HPS is to function permanently and to be able maintain a regime, adequate to the level of threats. Said in other words, to increase or decrease its functional parameters in the context of scale of the threat.
3. The HPS is to be predominantly "*object oriented*" than "*zonal oriented*".
4. The HPS is to be granted a relatively high level of autonomy, but the autonomy has to be balanced with reliable control.
5. The HPS is to be able to achieve flexible satisfaction of the management principles in a dynamic environment. Said in other words, the HPS has to maintain correct balance between relatively contradictory principles in the context of the situation.

One more "*scientific consideration*" should be mentioned. It comes for comprehension that, during the passage of a ship to/from the port area, the responsibility for her protection will be granted to the Navy. On the other hand, the responsibility for protection of the cargo during its delivery to/from the port will be granted to the Ministry of Interior. In both cases, the responsible institutions will be capable to minimize the risk of terrorist attacks by choosing more safety roots for passage and/or providing reliable protection measures in a typical environment of operating. The problem, which arises, is related to the fact that the transfer of the responsibility for cargo protection will be done in place and time when the cargo is most vulnerable – in the area of the port.

The following consideration is to be added:

6. The HPS is to compensate the shortcomings of the existing system, by providing adequate protection of ships and cargoes in the most vulnerable area: littoral approaches to the harbour, port area and adjacent urban area on shore.

On the base of the Bulgarian MSS current status, the following consideration has been formulated: The optimization of the HPS is to consider the current organization of the system. In other words, the process of optimization should not involve the idea of dramatic redefinition of the existing organization of the HPS or a new subordination of resources. The optimization has to focus mainly on the opportunity for improvement of the HPS functioning by achievement of a synergy effect of shared efforts on the base of correct co-operation. Practical recommendations are:

7. The HPS is to be in full compliance with the European, national, and international legislation.
8. The HPS is to consider existing "*status quo*" of the organizations involved (and interested) in harbour protection. The minimal changes of the "*status quo*" are recommended.
9. The optimization of the HPS has to provide correct solution of the organizational "*command and control dilemma*".

Taking into account that to a great extent the problems of the Bulgarian MSS current status are result of a situational approach to problems and the existence (and establishment) of too many interacting organizations, one more consideration should be added:

10. When optimizing the HPS, we should not establish one more organization, but unite the existing bodies (or their representatives) in a system.

On the base of the defined considerations, we elaborated a concept for optimization of the existing HPS. The leading idea of the concept is to achieve a viable HPS that, on the one hand, possess "*informational superiority*" to the possible threats (especially – the terrorism), and on the other – to satisfy management principles in accordance of the situation.

Both aspects of the concept are realized by establishment of network-organized HPS, which in a conflict situation is centralized on a level immediately above the scale of the terrorist threat.

The system is organized on the base of the existing network of Port Security Councils, established by the Bulgarian government *Ordinance No 53/2005* in response to the requirements posed by *ISPS Code*.[3]

The *Ordinance No 53* [7] establishes three security levels of readiness of the HPS. During the first level of readiness (the lower one) the system is maintained by the Port Security Councils mentioned above. When a higher degree of readiness is reported, the Councils are strengthened with additional assets (from the Ministry of the interior and the Navy). In the context of the situation and in accordance with a procedure, a senior person in the council is nominated (a chairman of the council). The nominated chairman is granted the right to exercise authority over the forces (assets) placed under command. The process of delegation of the command authority and the extent of the delegated authority are settled by a procedure.

In fact, the process described is the realization of the idea of centralization of a network organized HPS on a level immediately above the scale of the threat.

The technical base of the "new-born" centralized system is carried by a naval unit.

The area of responsibility of the system includes: littoral approaches to the harbour, port area and adjacent urban area on shore.

The components of the HPS are in fact joint forces belonging to different institutions and organizations. As we can see they provide "*object oriented*" protection. The "*zonal*" aspect of the protections remains a responsibility of the state institutions. Every institution exercises it in its particular area and/or functional direction of responsibility.

The "*command and control dilemma*" is settled by, on the one hand, a procedure for nominating of a senior person in the Harbour Protection Council, and on the other – a procedure which regulates the transfer of authority over the HMS (or a part of its components) among different bodies.

The results of the negative factors "*life-cycle*" analysis serve as a base for formulating the indicators that "*switch*" the levels of the readiness of the system and the transfer of the authority over the whole HPS (or a part of its components).

3 PROBLEMATIC FIELDS OF HARBOUR PROTECTION SYSTEM EDUCATION AND TRAINING

The current harbour safety and security related E&T process suffers the following practical problems:

- ship officers have little knowledge of the whole maritime safety and security system, whose functioning has become significantly more important in the light of the ISM [2] and the ISPS Code. Very often, the lack of this knowledge leads to demotivation of the main participants in the process of maritime transport;
- the training pursuant to the ISPS Code relies on the acquisition of standard tactical and technical methods of protection, which provides general standard basic knowledge and skills. Even though this is necessary, it contradicts the idea of pro-activeness and creative problem solving;
- the increased requirements of the STCW Convention, which already cover all the categories of maritime transportation system security officers, now demand a new system of training and a suitable learning environment;
- developing and maintaining such an environment requires significant expenses and the employment of a very well-prepared team, which is beyond the affordable for a maritime training institution.
- These problems are hyperbolized by some contradictions in the computer-assisted E&T process:
- developing and maintaining an expensive and complex environment for computer-assisted E&T is not affordable for a maritime training institution;
- the training in the issues of security should not be closed up only within the framework of the merchant marine;

– the future maritime officer should receive a much broader range of training in the issues of safety and security than the minimum required one in order to be an active organizer and an adaptive participant in the processes occurring in the World Ocean;
– the total time for training of the future maritime officers is reduced, and because of this the necessary balance must be stricken in their fundamental training in safety and security, and a new level of knowledge and skills must be achieved by applying both traditional and new training techniques.

These issues are practically a direct result of the lack of common methodology for preparing and conducting computerized training related to the general subject area of maritime security and harbour safety in particular.

4 FORMULATING REQUIREMENTS FOR PORT SECURITY SIMULATING COMPLEX

This part of the article describes overall logic underlying in the process of harbour responsible personnel E&T. It reflects two dominant concepts:

1. The E&T process serves the function of system adaptation (Lynch J. 1937).
2. Despite being a process of setting and maintaining desired behavior; the management process is based on reactions.

Notwithstanding that both concepts overlap, they pose some distinguishable requirements. In this context, some additional explanations are necessary.

Assuming that education is a process of adaptation, we have to take under consideration that "*adaptation takes place on at least three different levels*" (Gell–Mann 1994). On this base, we have defined three levels of the system adaptiveness: short-term adaptiveness, long-term adaptiveness, and evolutionary adaptiveness.

The short-term adaptiveness is a process of adaptation to the current situation. It is therefore a process of direct and situationally-oriented adaptation. It is performed predominantly by the way of functional adjustment. The process of functional adjustment very often is held by selection of a functional model (schema) that is relevant to the situation recognized.

The long term adaptiveness is a process of adaptation to relatively predictable future conditions of the environment. In addition to the functional adjustment, it is performed by the elaboration of structural prerequisites for functional adjustment to possible future situations. The practical execution of this process usually includes: making prognoses; analysis of possible situations; and elaboration of adequate reactions.

The evolutionary adaptiveness is observed in unpredictable situations. It is therefore performed by elaboration of structural prerequisites for the necessary system's properties for adaptation in cases of emergency.

It is a good idea to make a parallel between, on the one hand, the three levels of adaptation, and on the other – the three levels of management (tactical, operational and strategic). Going one step further, we can state to a great extent of certainty that the E&T process has to provide prerequisites for the three types of adaptiveness.

Assuming that the harbour protection management process is based on reactions, the scopes of different types of management can be summarized as follows:

1. Strategic management is to achieve better alignment of organizational policies in response, in a long-term time scale, to changes in the external environment and in the organization itself (the internal environment).
2. Operational management is the process of designing, executing, and controlling an organization's operations that convert its resources into desired end-state, and implement a selected strategy. This type of management responds in a relatively short-term time scale to predictable changes in the external environment.
3. Tactical management is the process of quick and accurate assessment of the situation and elaboration of an appropriate response.

The particularity of the three levels of management advocates the necessity of three distinguishable types of E&T.

Considering on the one hand, the comprehension that one's reactions to a particular situation are an original "*cocktail*" of previous experience and the ability to estimate and respond to the particularity of the situation, and on the other – the parallel between levels of adaptiveness and levels of management, we can formulate the focuses of the different levels of E&T process.

The initial E&T process (tactical) has to establish behavioural models necessary for quick response to a familiar situation. In other words, the purpose is to give the trainee an adequate "memory". For this reason, the basic level of the port security simulating complex has to provide models of typical situations in typical environments.

The next stage of E&T process (operational) is to make the trainee to "*overcome*" the framework of the behavioural models learned, to "*recognize*" the specificity of the situation, and to elaborate proper (which means – specific) response. In order to support this idea, the port security simulating complex has to provide models of non-routine situations in non-routine environments.

The last level of the E&T process (strategic) explores the idea to give the trainee the ability to make logical relations in an "unrelated" processes and events, to recognize the patterns that they have in common and "*cause – effect*" relations, and on this base, to elaborate basic and widely applicable behavioural models.

Taking into account that computer-assisted E&T basically provides simulations which model the conditions of performing system functioning, obviously, simulators have to be flexible enough in order to be able to "*shift*" the accents of the overall E&T process.

This understanding of port security E&T process is the base for formulating the following requirements to the overall M&S system:

1. The virtual environment for the HPS's E&T process has to provide both "*technical experience*" and "*management practice*" for the personnel. The "*sub-recommendations*" are:
   - the simulators have, on the one hand, to be in full compliance with the equipment, and on the other – to "*reflect*" the existing organization of the HPS;
   - both the simulators and the M&S methodology are to be flexible enough in order to "*shift the emphasis*" of the training from "*predominantly technically oriented*" to the "*predominantly management-oriented*".
2. The virtual environment for the HPS's E&T process has to model a great variety of possible safety and security situations.

Any reaction in a particular situation is based on behavioural models which have "*worked*" in similar situations. The lack of real practical experience of the HPS leads to the idea to provide the HPS with an "*artificial memory*". This means to use an opportunity to acquire data of situational games in virtual environment, to analyze the data collected, to derive indicators for recognition the particular situation, and to suggest a management decision. The recommendation is:

3. The simulators have to provide an opportunity for "case management" by modeling specific situations, acquisition and analyzing data and suggesting particular course of action.

Taking into account, on the one hand, the dynamic nature of the security environment, and on the other – the abstract charge of the social comprehension for "*safety*", the next recommendations are:

4. The simulators have to provide an opportunity for upgrading and modernization.
5. The M&S methodology and the supporting base (databases, software, workstations, etc.) are to be flexible enough in order to allow their adjustment to the changeable organization of the HPS.

The necessity of the simulators and M&S methodology flexibility can be developed in one more direction – the idea to use virtual environment for scientific purposes. The possibility to test different realizations of the HPS's architecture is to be provided by specialized software.

The second conclusion suggests that there are distinctive "*accents*" of the E&T process.

Preliminary preparation is performed on the basis of typical scenarios. The E&T process is carried out in circumstances posed by "*an unidentified risk*". Logically, the recommendation is:

6. The simulators have to support the following activities:
   - development of typical scenarios;
   - development of typical reactions in context of the typical scenarios;
   - examination of the HPS's functioning in the environment described by the typical scenarios.

The simulators support the following activities: training, planning, and research.

The recognition of the negative factor as "*a risk*" finalizes the preliminary preparation on the basis of typical scenarios and the focus of the E&T process shifts to preliminary preparation on the basis of concrete scenarios. The recommendation is:

7. The simulators and the M&S methodology have to be able to select scenarios adequate to the current situation and to provide reliable prognosis for the possible development of the situation.

The last conclusion of the analysis led us to the idea, that the short-term adaptation process becomes dominant in relation to any other HPS's function. In fact, after the recognition of a negative factor as "*a risk*", the other activity, in practice, stop and "*melt*" into the background of the elaboration of a response to the current situation. Obviously, the paramount role of the short-term reactions suggests that the E&T process first has to provide "*technical experience*" for the operative personnel and "*management practice*" for the low hierarchical level managing staff, and only after that – to put attention on the preparation of long-term oriented adaptive reactions. This motive led us to the idea to try to answer the question if there is any relation between, on the one hand, the different accents of the E&T process, and on the other – the safety and security concepts.

Professor Donna J. Nincicl provides an interesting metaphor explaining the difference between the safety and the security concepts: "*safety is doors open to allow free access for escape or rescue in a dangerous or unsafe situation. Security, on the other hand, is doors closed to prevent access to those who might wish to do us harm*" (Nincicl 2007). Assuming, that "*security can be considered protection from active malicious agents*" and "*safety, on the other hand, can be considered protection from accident, maritime casualties…*", we went one step further and say that safety is "*effect-oriented countering*" concept, which means – short-term oriented. In the contrary, security is "*cause-oriented countering*" concept or – long-term oriented. Logically, the E&T process has to consider that safety related E&T is the basic prerequisite for the security related E&T. The recommendation is:

8. The M&S methodology has to provide correct balance between the safety and security orientations of the E&T process.

5 CONCEPTUAL MODEL FOR FLEXIBLE SIMULATOR ARCHITECTURE

The conceptual model of the "*simulating complex*" is presented in *fig. 1*.

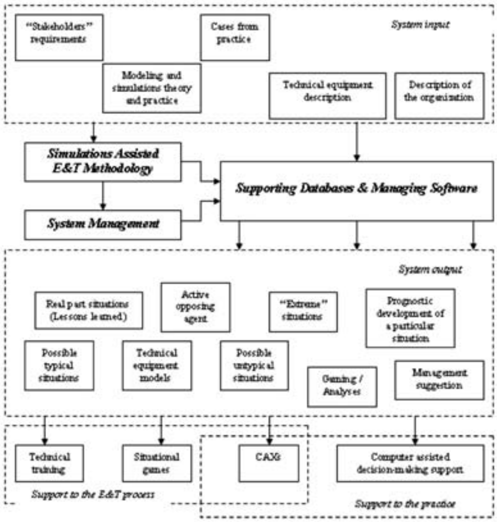

Figure 1. Flexible architecture for Port Security Simulating Complex.

The system "*input*" includes:

- "*stakeholders*" requirements;
- modelling and simulation theory and practice;
- cases from practice;
- technical equipment description;
- description of the organization.

The "*input*" serves the following functions: elaboration of a simulations methodology and data acquirement.

Taking into account a particular purpose of the E&T process and related modeling and simulations methodological procedures, the managing body (system) of the E&T process formulates the desired "*output*" products. This task is supported by a specialized for the case software.

Different combinations of the products are "*unified*" by the managing system (using the support of related managing software) in different E&T forms and/or forms of providing modelling and simulations support to the decision-making process.

At tactical level the simulating complex has to be aimed to mono-agency task training – fire brigade, police, port security staff, navy etc.

In accordance with the operational level of simulations simulation process has to be aimed to the representation of wide spectrum of operations. The requirements that the model has to follow are different than the previous (tactical) level ones. Because of the nature of operations, an important part of this level is the possibility to create a simulation of a crisis management system. The main purpose of the system is to shorten the time needed to make up the optimum cleanup decision, in order to reduce population losses, financial and ecological damage and other types of direct and indirect damage. In this way the simulation system has to be a powerful tool for the support of emergency response decision making. The system should coordinate and control the activities of the units involved and provide information to all of the participants of decision making team.

The most common tasks for modelling at the operational level are:

- using electronic charts with possibility to edit, add and delete objects and information;
- portraying operational plans on the charts;
- route and resource planning;
- monitoring the resource motion;
- assessing response resources;
- comparative analysis of different plans, etc.

The last but not least is the application of M&S at the strategic level. At this level, the undertaken actions are similar to operational level, but generally they are more global and wide ranged:

- displaying strategic plans on the charts;
- resource planning;
- monitoring the resource motion;
- assessing response resources;
- comparative analysis of different plans, etc.

6 CONCLUSION

Even a passing glance on the proposed conceptual model of the Port Security Simulating Complex inspires the sentiment that the system proposed is a kind of "*perpetuum mobile*" for the moment.

Being conscious about the "*utopian*" charge of the concept proposed and keeping in mind that many things that were "*fiction*" in the past are parts of our life nowadays, we state that the real problem for elaboration of a similar M&S system is not "*technical*", but it is related to our willingness to solve it.

Its establishment in practice will help us to achieve the main goal of education and training – preparation of highly motivated and well educated and trained port security personnel.

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8.5
Problem of stopping vessel at the waypoint for full-mission control autopilot

L. Morawski
Gdynia Maritime University, Gdynia, Poland

V. Nguyen Cong
Vietnam Maritime University, Haiphong, Vietnam

ABSTRACT: The paper presents a controlling method to control vessel of a full mission autopilot at the transitional phase when vessel reduce speed from navigation speed down to manoeuvring speed while she accesses to the manoeuvring waypoint, where the vessel is started control in manoeuvring mode. The vessel is controlled by three propellers: the bow thruster, the stern thruster and the main propeller. The autopilot is designed with 5 fuzzy logic controllers. It works in Matlab-Simulink and tested on a scaled physical model of a tanker in the lake environment.

1 INTRODUCTION

Nowadays, many ships are equipped with thrusters to support manoeuvring activities. By using these thrusters, the full mission autopilot can control vessel fully automatic from a quay to other quay.

During a voyage, the controlling vessel can be divided into 3 phases: sailing phase (when vessel runs at open sea); manoeuvring phase (when vessel runs in narrow and resisted water); transitional phase (when vessel changes from sailing mode to manoeuvring mode).

In the transitional phase, the vessel is reduced speed from sailing speed (at which, the vessel can be controlled just by the rudder) to the manoeuvring speed (at which, the rudder's effect is too small and vessel mainly control by thrusters and main propeller). The autopilot's task in this phase is to reduce the vessel speed to the required speed (manoeuvring speed) during approaching to the waypoint and also keep the vessel moving on the set path with the set heading.

This paper presents the algorithm and the experiences results by using simulator and scaled model of the autopilot, which is designed and researched by the authors (Leszek et al. 2008).

2 THE OBJECT OF CONTROL

The training ship "Blue Lady" is the floating, autonomous scale model of the VLCC tanker. It is used by the Foundation for Safety of Navigation and Environment Protection at the Silm Lake near Ilawa in Poland for training navigators. The ship is built of the epoxies resin laminate in 1:24 scale. It is equipped with battery-fed electric drives and the control steering post at the stern. The model is equipped with the main propeller, a rudder, two tunnel thrusters, and two azimuth pump thrusters which can be rotated within limited angle ranges. The controller presented in the paper just controls two tunnel thrusters and the main propeller for manoeuvring tasks. The arrangement of the model is shown in Figure 1, while the main characteristic data are given in the Table 1.

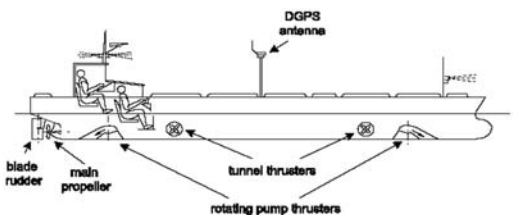

Figure 1. The arrangement of the model "Blue Lady".

Table 1. The main characteristic data of the model.

Length over all LOA	13.78[m]
Beam B	2.38[m]
Draft (average) – load condition Tl	0.86[m]
Displacement – load condition D	22.83[T]
Speed	3.10[kn]

3 THE REFERENCE FRAMES AND THE DEFINITIONS

There are two reference frames used in control. They are Geographic reference frame ($x_n y_n$) and Body reference frame (Fig. 2).

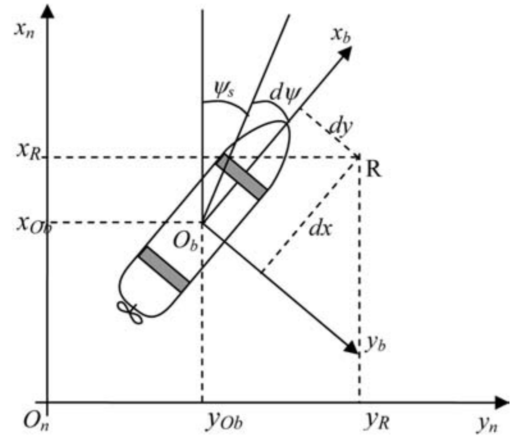

Figure 2. Reference frames.
R – reference point, required position of the vessel
dx – position deviation in x-axis of b-frame
dy – position deviation in x-axis of b-frame
ψs – set heading
dψ – course deviation.

Geographic Reference Frame ($x_n y_n$ or n-frame): The coordinate system $x_n y_n$ is defined relative to the Earth reference ellipsoid (World Geodetic System 1984). In this coordinate system the x-axis points towards true North, while the y-axis points towards East (Fosen 2002).

Body Reference Frame ($x_b y_b$ or b-frame): This is moving coordinate frame which is fixed to the vessel. The origin O_b of the coordinate system is chosen to coincide with the center of gravity (CG) when CG is in the principal plane of symmetry. The axes are defined as x-longitudinal axis, directed from aft to fore and y-transversal axis, directed to starboard (see Fig. 2) (Fosen 2002).

The position of vessel is fixed by GPS in n-frame while the signals for control (deviations) are measured in b-frame. The transfer functions of coordinates and velocities between these frames as following:

$$\begin{aligned} [x_b \quad y_b \quad \psi_b]^T &= R_b^n [x_n - x_{Ob} \quad y_n - y_{Ob} \quad 0]^T \\ [u \quad v \quad r]^T &= R_b^n [\dot{x}_n \quad \dot{y}_n \quad r]^T \end{aligned} \tag{1}$$

where

$$R_b^n = \begin{bmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}^{-1} \tag{2}$$

Reference point R: This is a point on which the vessel position has to be maintained. The vessel movement will be controlled through this point (Vinh 2007).

4 ALGORITHM OF CONTROL AND AUTOPILOT DIAGRAM

The diagram of the autopilot is shown in Figure 3. The *Positioning* regulator has task of controlling main engine and thrusters to keep vessel at the *reference point* with the set heading. The *Trajectory* regulator has task to steer the ship along a strait path segment. The *Trajectory* controls rudder and main engine of the ship. Depending on the control mode, the *Signals selector* block switches and connects the output signals of the regulators to the propulsion system.

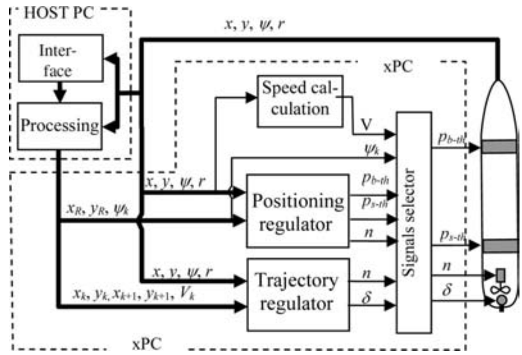

Figure 3. Regulator diagram.

As mentioned in the section 1, in the transitional mode, the autopilot has to 1) keep the vessel course stable in the path segment direction and the vessel movement stable on the path segment; 2) control the braking force to obtain the speed that is within the manoeuvring speed range when the vessel arrived exactly at the waypoint.

The braking up of a vessel is carried out in 2 steps:

Step 1: Starting braking up at the braking distance $d_{braking}$. When the distance from the vessel to the waypoint is less than or equal $d_{braking}$, the auto pilot changes the control mode from trajectory mode to transitional mode.

Step 2: Adjusting the braking up force. In this step, the autopilot controls the rudder, thrusters to keep the vessel moving on the set path with the required heading and it also controls the main engine to reduce the vessel speed.

The algorithm used in each steps is presented in detail in the next subsections.

4.1 *Calculating a breaking distance $d_{braking}$*

The braking distance $d_{braking}$ is the distance to the first waypoint of the manoeuvring segment, at this distance the autopilot should change from the trajectory mode to the transitional mode to access the waypoint correctly (Fig. 4).

In this autopilot, the braking distance $d_{braking}$ is calculated by using the following formula

$$d_{braking} = au^4 + bu^3 + cu^2 + (d + f)u + e \tag{3}$$

In the formula (3), u is the surge of the vessel. The coefficients of equation (3) are defined from the results of the experiment. The coefficient f is the time taken to change the engine mode of the vessel. Other coefficients *a, b, c, d, e* are defined by the experiment as

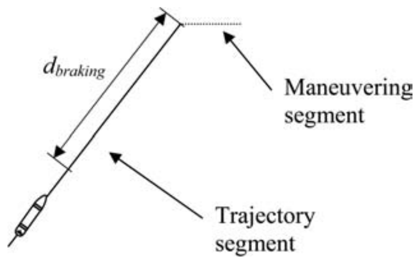

Figure 4. The braking distance $d_{braking}$ in transitional phase.

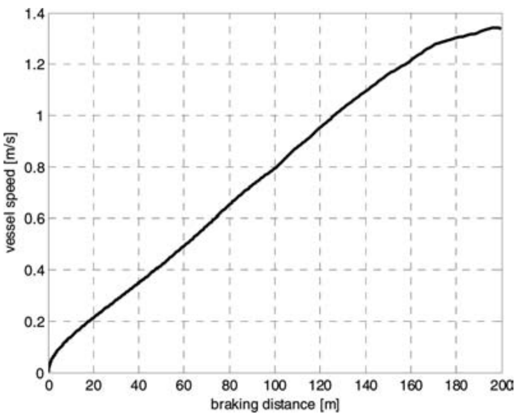

Figure 5. The relation between the braking distance $d_{braking}$ and speed of the Blue Lady model when the engine mode is set to dead slow astern.

following: "Vessel is full loading, runs ahead at maximum speed in the wind on a straight path. At a moment, change engine to dead slow astern then record the vessel speed and the passing distance of vessel until the vessel completely stops."

The graph in Figure 5 is an example of the experiment result. On the basis of the recorded data, the coefficients of formula (1) are defined by using Horner's method.

The dead slow astern engine mode was used for transitional mode after many experiments on the lake with the *Blue Lady* model. During braking up, the engine runs astern while vessel moves forward, the chaotic water flow increases and causes abnormal movement of the vessel. If a higher engine mode is used, the chaotic flow will be stronger then the thrusters and the rudder will be not strong enough to manage the vessel.

4.2 *Adjusting the braking up force*

In the transitional phase, the *Processing* block sets and controls the *reference point R* moving along the path segment; and sets the heading as same as direction of the path segment (see Fig. 6).

When the vessel speed is enough for rudder effect, the *Trajectory* regulator controls the rudders to support

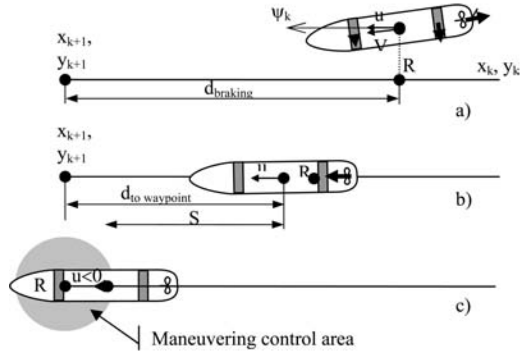

Figure 6. Braking up a vessel.

thrusters keeping the vessel course. When the speed is too low, the signal from *Trajectory* regulator is cut off.

The *Positioning* regulator controls the vessel heading by the thrusters and braking force by main propeller to obtain vessel speed within the manoeuvring speed range when the vessel reaches the waypoint.

As mentioned in subsection 4.1, the braking force is fixed by the engine mode dead slow astern. So, to adjust vessel speed, the autopilot just changes the engine vessel to dead slow astern, stop or dead slow ahead mode. The engine mode is selected by comparing the actual distance from vessel to the waypoint with the *expected passing distance S* of the vessel.

The *expected passing distance S* is calculated by following formula:

$$S = \frac{u_2^2 - u_1^2}{2a} \tag{4}$$

where

u_1: actual vessel surge

u_2: the required speed (surge) at the waypoint, it should be within the manoeuvring speed range. In this autopilot, the value of u_2 is set at 0

a: average acceleration of a vessel while speed changes from u_1 to u_2

S: the distance which vessel passed while speed changes from u_1 to u_2.

As mentioned above, the engine mode for braking is fixed at dead slow astern so the braking force may be treated as a constant force. Hence, the average acceleration a can be treated as constant and it can be calculated as:

$$a = \frac{u_{t2} - u_{t1}}{t_2 - t_1} \tag{5}$$

The *Processing* block reads vessel surge every sampling period and calculates acceleration a as formula (5). From values of a, u_1 (actual surge), u_2 (required surge), the *Processing* block calculates the *expected distance S*.

Table 2. Set path of braking up experiments.

Experiment No.	Waypoint A X[m]	Waypoint A Y[m]	Waypoint B X[m]	Waypoint B Y[m]	Speed[m/s]/ engine mode
No. 1	75768	71540	75314	71540	1.31/full ahead
No. 2	75768	71540	75314	71540	1.00/half ahead
No. 3	75768	71540	75314	71540	0.70/ slow ahead
No. 4	75768	71540	75314	71540	0.50/ d.slow ahead

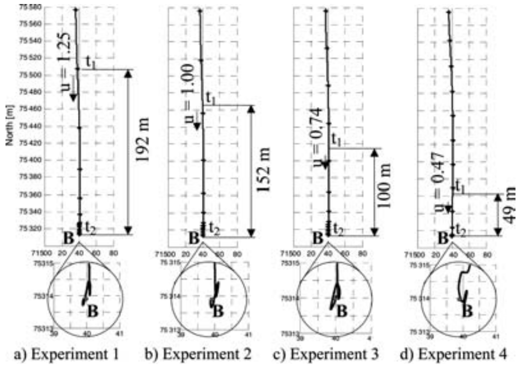

Figure 7. Track of the vessel in the braking up experiment using computer simulation. Position marked every 60 s; u – surge of vessel at the starting of the transitional mode.

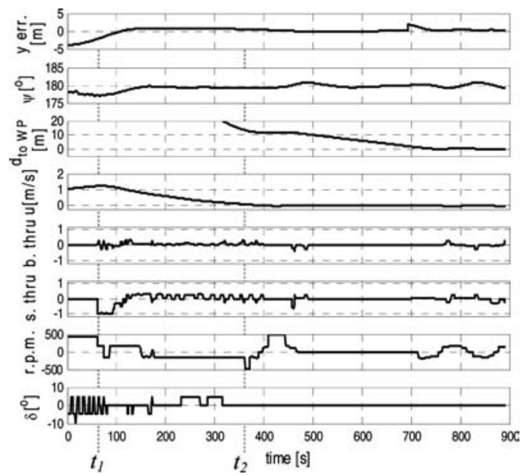

Figure 8. Recorded data of the braking up experiment 1 $d_{to\ WP}$ – the distance from the vessel to the target waypoint.

5 EXPERIMENTS AND RESULTS

5.1 *Experiment using simulator*

The experiments on braking up a vessel were performed using computer simulation as well as the model in real environment. In computer simulation, a vessel was tested braking up from four different speeds with respect to four engine modes: full ahead, half ahead, slow ahead and dead slow ahead (Table 2).

In the experiment, the vessel was running from waypoint A(75768, 71540) to waypoint B(75314, 71540) on the course of 180° (Table 2). The autopilot's task was to stop the vessel at waypoint B. While stopping vessel, the heading had to be kept at 180° and the vessel track had to be kept close to the path segment AB.

While the vessel was running steadily along path segment AB, the *Processing* block calculated braking distance $d_{braking}$ basing on the actual vessel speed using formula (3). Depending on the instant speed, these distances $d_{braking}$ were 192 m, 152 m, 100 m and 49 m with respect to the speed of 1.25 m/s, 1.00 m/s, 0.74 m/s and 0.47 m/s (Fig. 7).

When the distance from the vessel to waypoint B was less than $d_{braking}$, the autopilot changed the control mode from the trajectory mode to the transitional mode. From this moment t_1 in Figure 7, the main engine was controlled by the *Processing* block to adjust braking force; two thrusters were controlled by the *Positioning* regulator to maintain vessel course; the rudder was controlled by the *Trajectory* regulator until the vessel speed was less than 0.1 m/s.

When the vessel speed reached the manoeuvring speed range or the vessel was in manoeuvring area around waypoint B, the autopilot changed the control mode to the manoeuvring mode (t_2). In experiments 1, 2 and 3 (Fig. 7 a, b, c), the vessel speed reached manoeuvring speed at about 10m before the target waypoint B (position of t_2 in Fig. 7). From this moment t_2, the vessel was controlled using the manoeuvring mode and it took about five minutes to move to the waypoint B.

In the experiment 4, the vessel approached the maneuvering area of waypoint B but the speed was higher than the maneuvering speed. In this situation, the autopilot changed also the control mode to the manoeuvring mode. After that, the *Positioning* regulator immediately set the main engine to full astern mode to stop the vessel quickly (see Fig. 11).

The Figures 8–11 show the recorded parameters of the four experiments. The vessel was stopped at the waypoint B with position deviation less than 0.5 m and the heading drift in these slowdown manoeuvres was less than 2°.

5.2 *Experiment using scaled model Blue Lady*

The next experiment was performed with the *Blue Lady* model on the lake. In this experiment, the vessel was running from waypoint A(75273, 71480) to waypoint B(74952, 71754) with the engine mode slow ahead (r.p.m = 240 ∼ V = 0.6 m/s). The task of the autopilot was to reduce the vessel speed to the manoeuvring speed at waypoint B. At waypoint B, the vessel was turned to the heading of 150° and then moved to waypoint C(74978, 71780).

At the speed of 0.6 m/s, the braking distance was 72 m (using formula 3). When the distance from the

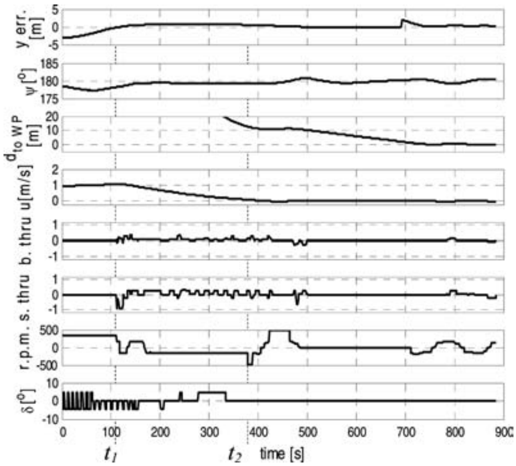

Figure 9. Recorded data of the braking up experiment 2 $d_{to\ WP}$ – the distance from the vessel to the target waypoint.

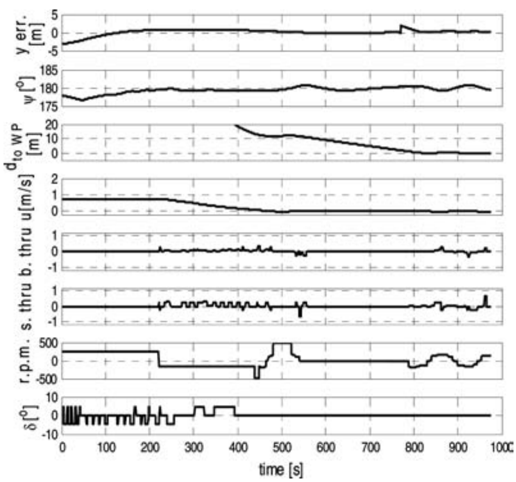

Figure 10. Recorded data of the braking up experiment 3 $d_{to\ WP}$ – the distance from the vessel to the target waypoint.

vessel to waypoint B was less than 72 m, the autopilot changed the control mode to the transitional mode. The *Processing* block controlled the braking force by the main engine r.p.m., while the *Positioning* regulator and *Trajectory* regulator controlled the heading by the two thrusters and the rudder.

At the moment t_2, when the model was within the manoeuvring range of the waypoint B, the autopilot changed the control mode to the manoeuvring mode. From t_3 to t_4 the vessel turned to the heading of 150° as required in the set path.

From t_4 to the end of the experiment, the vessel moved translationally to waypoint C with the heading of 150°.

The recorded data is shown in Figure 13. Compared to the results obtained using computer simulation, the thrusters were working harder. The reason of this is that the simulator did not simulate well the effect of

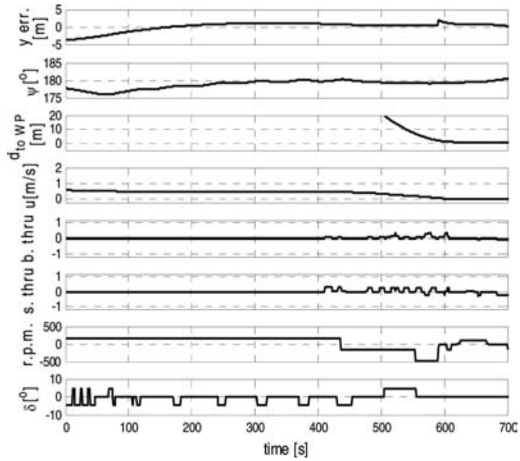

Figure 11. Recorded data of the braking up experiment 4 $d_{to\ WP}$ – the distance from the vessel to the target waypoint.

Table 3. Set path of experiment No. 5.

Way-points	X [m]	Y [m]	Set speed [m/s]	Set heading [°]	Control mode
A	75273	71480			
B	74952	71754	A → B: 0.6	A → B: 130 at B: 150	Trajectory & Transitional
C	74978	71780	B → C: not set	B → C: 150	Manoeuvring

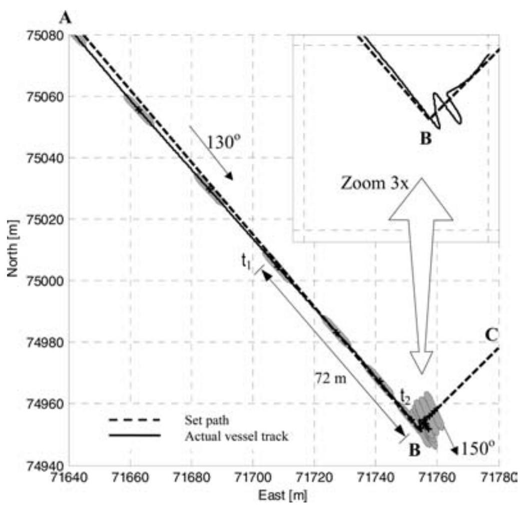

Figure 12. Experiment No. 5 from second 1000th to 1825th. The positions are marked every 60 s.

a chaotic water flow. In the experiment on the lake, the chaotic water flow had a very strong effect on the model. In many experiments, the thrusters were not powerful enough to manage the model while braking up it by full astern or half astern engine. That is why the autopilot brakes up a vessel only by dead slow astern engine.

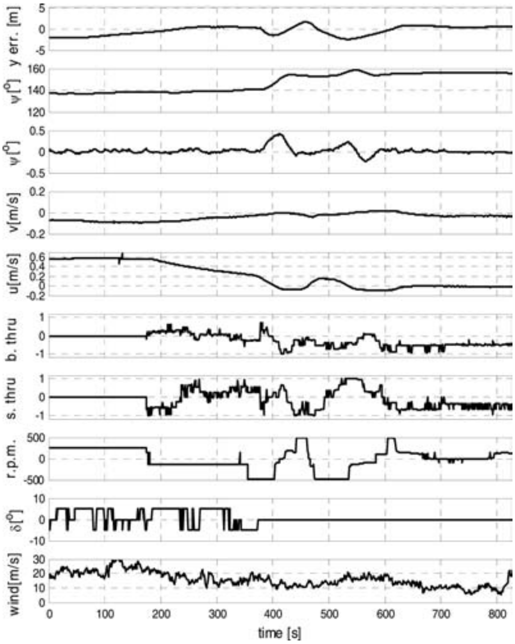

Figure 13. Recorded data of experiment No. 5 from second 1000th to 1825th.

6 CONCLUSIONS

In simulation experiments, the model was stopped completely with the position deviation less than 0.5 m around the set waypoint. In the experiment on the lake in windy conditions, the final position deviation was about 2 m. Compared to the length of the model (13.75 m), the deviations are acceptable in practical manoeuvrings. The heading deviations of the model in this manoeuvre were less than 5o in all experiments.

When vessel runs at full speed, to stop it the passing distance is 192 m (about 15 lengths of the vessel). It is also can be accepted in the practice navigation.

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8.6
On the control of CPP ships by steering during in-harbour ship-handling

H. Yabuki
Tokyo University of Marine Science and Technology, Tokyo, Japan

Y. Yoshimura
Hokkaido University, Hakodate, Hokkaido, Japan

ABSTRACT: This paper describes the results of experimental and simulation studies that aimed at developing effective control methods for single-CPP single-rudder ships during the coasting manoeuvre and the stopping manoeuvre. In order to improve the manoeuvrability of CPP ships under coasting, the authors performed full-scale experiments and confirmed that CPP ships under coasting using the Minimum Ahead Pitch (MHP) of CPP are controllable by steering. A simulation study was also conducted to evaluate the ship-handling method during the stopping manoeuvre that applies a turning moment to the ship by the maximum rudder angle steering prior to the reversing operation of the CPP and it is confirmed that CPP ships can be controlled sufficiently by the proposed method.

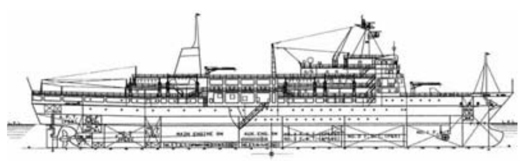
1 INTRODUCTION

It is well known that a controllable pitch propeller (CPP) can provide smooth speed control. On the other hand, in case of ships with single CPP and single rudder, the difficulties of coasting manoeuvre and stopping manoeuvre are reported (Takeda 1992, Yabuki 2006).

During coasting manoeuvre of CPP ships with propeller pitch feathered to zero, the rudder force reduces significantly and CPP ships are difficult to control their head turning motion by steering especially under windy condition. Furthermore, during the stopping manoeuvre of CPP ships, an additional unstable yaw moment is often exerted, which introduces a significant reduction in manoeuvrability, and, under this condition, it is difficult to control their head turning motion by steering.

In order to improve the manoeuvrability of CPP ships at coasting, the authors propose the use of the Minimum Ahead Pitch (MHP) of CPP. The MHP is the smallest blade angle of CPP for ahead propulsion which ensures adequate steerage. The authors conducted full-scale experiments using a 5,884 G.T. single-CPP, single-rudder training ship to confirm the effectiveness of the MHP operation in coasting.

Figure 1 shows the general arrangement and principal particulars of the test ship.



Principal Particulars	
Hull	
Length: Lpp (m)	105.00
Breadth: B (MLD, m)	17.90
Depth: D (MLD, m)	10.80
Cb	0.5186
draft: d (m)	5.96
Propeller (CPP)	
Prop. Brade No.	4
Prop. Dia.: Dp (m)	4.70
P.R. (Brade Angle)	1.050 (25.5°)
Rudder (Flap Rudder)	
Ar (m^2)	10.034
Ar/Ld	1/63.4
Aspect Ratio	1.865

Figure 1. Principal particulars of the test ship.

A simulation study using the MMG type mathematical model was performed in order to investigate the in-harbour ship-handling method to control the unstable stopping motion of CPP ships. The test ship was the same CPP ship as stated above. Based on the results of the simulation study, the authors propose an effective ship-handling method that applies a turning moment to the ship by the maximum rudder angle steering prior to the reversing operation of the CPP.

2 CHARACTERISTICS OF TURNING MOTION OF CPP SHIPS DURING STOPPING MANOEUVRE AND COASTING

2.1 *Turning motion during stopping manoeuvre*

The test ship is equipped with a CPP and can also reverse the main engine directly. This system makes it possible to perform a comparative experiment using the same hull and engine under the same condition to investigate the difference of a turning motion during the stopping manoeuvre between CPP and FPP (Fixed Pitch Propeller) ships.

Full-scale stopping tests were performed under almost the same condition in deep water in both CPP and FPP operation modes. As light breeze was observed during the experiment, the initial course was set into the wind for all stopping tests. In Figure 2, the final head turning angle (Ψ) when the ship is stopped is plotted against the initial advancing constant $J_{S0}(=U_0/(n \cdot P))$ both in the CPP mode and in the FPP mode. In the figure, the results of the stopping manoeuvre in which the propeller was reversed and the maximum rudder angle was applied simultaneously are plotted in addition to those with the rudder amidships.

In the FPP mode, the test ship exhibits the typical stopping motion of a right turning single propeller ship, i.e. she turns her head to the starboard steadily and the direction of her turning motion can be sufficiently controlled by steering. On the other hand, the turning motion in the CPP mode proved to be less stable than that in the FPP mode and the effect of steering to control the direction of turning motion was not observed. The direction of turning motion in the CPP mode seems to be fixed mainly by the relative wind direction at the initial stage of propeller reversing.

From the above-mentioned results, it is assumed that the direction of turning motion of CPP ships is fixed by the head turning moment at the initial stage of propeller reversing.

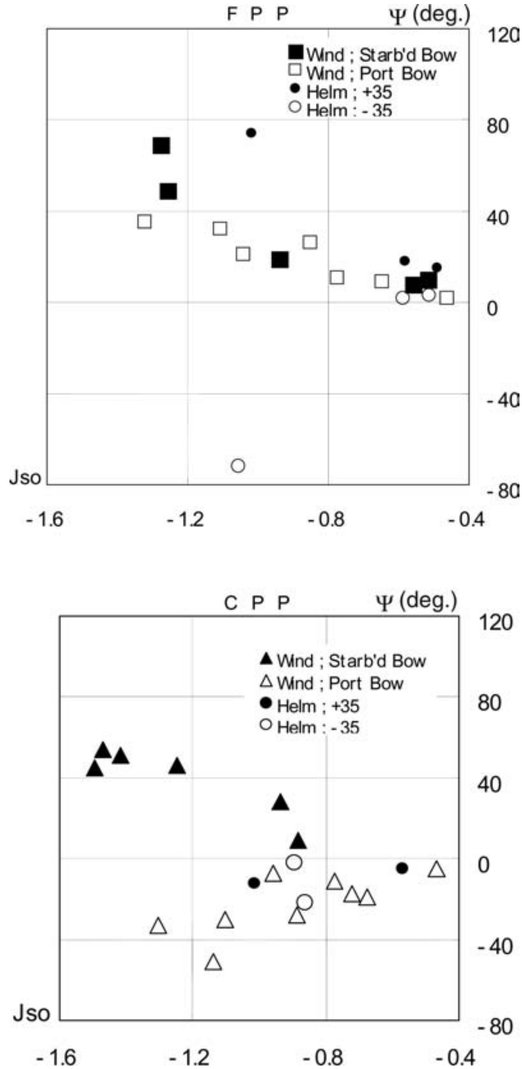


Figure 2. Comparison of the head turning angle between FPP and CPP.

2.2 *Turning motion during the coasting manoeuvre*

The authors performed course keeping tests using the same CPP ship as mentioned above in order to compare the effects of steering control under the coasting manoeuvre between the propeller pitch zero operation and the MHP operation. The time history of heading, rudder angle, CPP blade angle and ship speed are plotted in Figure 3.

In the coasting manoeuvre under the propeller pitch zero operation, the test ship turns her head into the wind even though the wind was very weak (1 m/s) and her head turning motion can not be controlled by steering with the maximum rudder angle. Since the obtained results agree with the results of other experiments (INOUE 1992) qualitatively, these characteristics seem to be common among ships with a single CPP and a single rudder.

This manoeuvring difficulty may be due to the pitch distribution of blades at propeller pitch zero operation. Though the pitch around the boss is maintained to the advance side, the pitch around the tip is changed to the reverse side at propeller pitch zero operation and the unstable flow which reduces the rudder force is generated around the stern.

On the other hand, in the case of the coasting manoeuvre with the MHP, the test ship can keep her original course under strong wind conditions (6 m/s) by applying the appropriate helm. This experimental result seems to prove the effectiveness of the MHP operation under the coasting manoeuvre and that CPP ships under coasting using the MHP can keep and control their heading by steering.

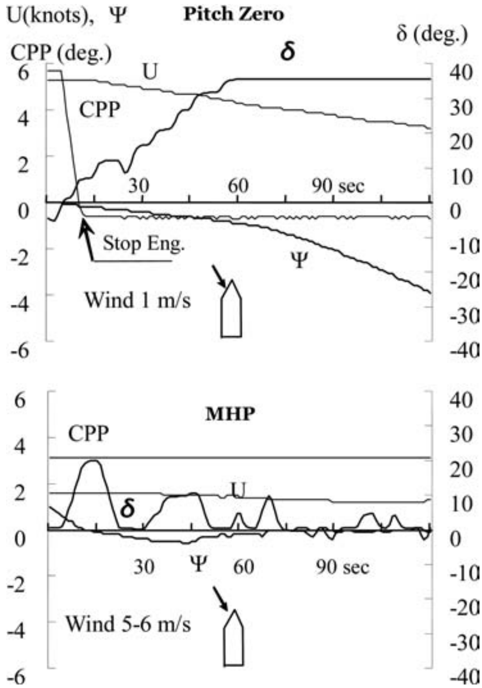


Figure 3. Comparison of the course keeping ability between pitch zero operation and MHP operation.

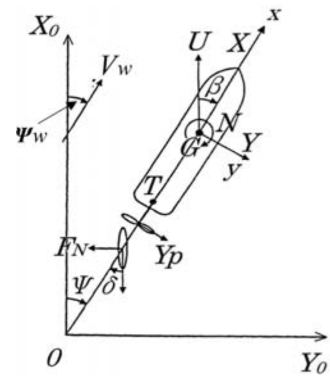


Figure 4. Coordinate system.

3 CONTROL OF TURNING MOTION OF CPP SHIPS DURING STOPPING MANOEUVRE

3.1 *Stopping motion prediction of CPP ships*

The stopping motion of CPP ships is predicted using the MMG type mathematical model. The mathematical model can be described by the following equations of motion using the coordinate system in Figure 4.

$$\left.\begin{aligned} m\dot{u} - mvr &= X \\ m\dot{v} + mur &= Y \\ I_{zz}\dot{r} &= N \end{aligned}\right\} \tag{1}$$

The hydrodynamic forces can be expressed by the following equations.

$$\left.\begin{aligned} X &= X_H + X_P + X_R + X_W \\ Y &= Y_H + Y_P + Y_R + Y_W \\ N &= N_H + N_P + N_R + N_W \end{aligned}\right\} \tag{2}$$

where, m = mass of ship; I_{zz} = moment of inertia of ship in yaw motion; u, v, r = axial velocity, lateral velocity, rate of turn respectively.

The terms X, Y and N represent the hydrodynamic forces and moment. The subscripts H, P, R and W refer to the hull, propeller, rudder and wind force respectively.

The detailed expression of hydrodynamic forces and moment on the hull, propeller, rudder and wind are available in the references (Yabuki 2006, Yabuki 2007).

The hydrodynamic derivatives and coefficients for simulation were measured by the captive model tests such as CMT, oblique towing tests, and rudder tests using 1/24.48 ($Lpp = 4.29$ m) model. The hull force and moment coefficients are measured by CMT and oblique towing tests. As for the forces and moment induced by propeller reversing, the thrust coefficients were estimated using the 4 quadrant POT result on the reversing blade angle and thrust data on MAU charts. The thrust deduction coefficient was obtained by the model test. The lateral force and moment were obtained from the captive model tests on the reversing blade angles. Rudder force and moment coefficients are measured by rudder tests and the interactive coefficients between hull and rudder are obtained from the gradients of these coefficients. The wind force and moment coefficients were derived from a wind tunnel test using the 1.5 m length model. The hydrodynamic derivatives and coefficients for simulation are available in the references (Yabuki 2006, Yabuki 2007).

The accuracy of the mathematical model of the test ship was confirmed by comparing the simulation results with those of full-scale experiments as shown in Figure 5. In the stopping test, turning moment is applied to the test ship by maximum rudder angle steering prior to making slow astern operation while proceeding at 4 knots. Although the time history of ship speed indicates some discrepancy between simulation and actual measurement, the predicted changes of heading and trajectory are in good agreement with the measured results. Thus, it seems reasonable to consider that the proposed simulation model represents the stopping motion accurately.

3.2 *Steering control of CPP ships during stopping manoeuvre*

As described in section 2.1, the direction of turning motion of CPP ships during the stopping manoeuvre seems to be determined by the yaw moment at the initial stage of propeller reversing. Therefore, the authors propose the stopping manoeuvre to control the head turning motion of CPP ships that applies turning moment by the maximum rudder angle steering prior

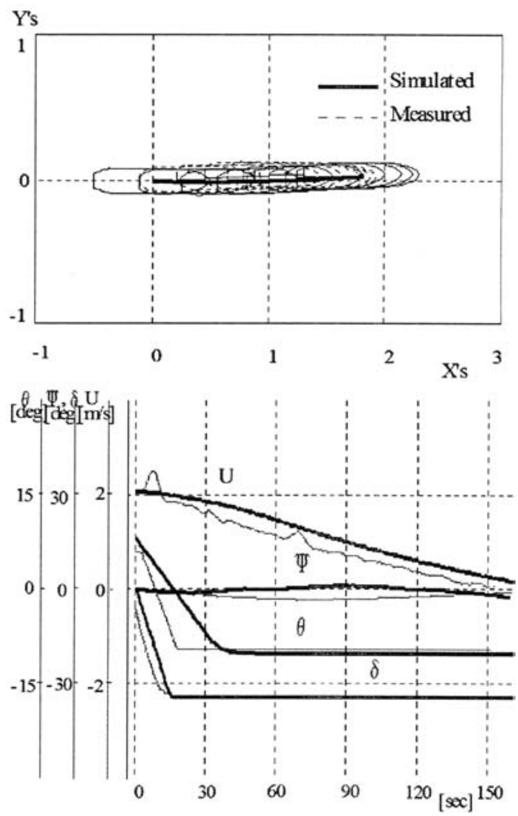


Figure 5. Comparison of the stopping motion between measured and simulated.

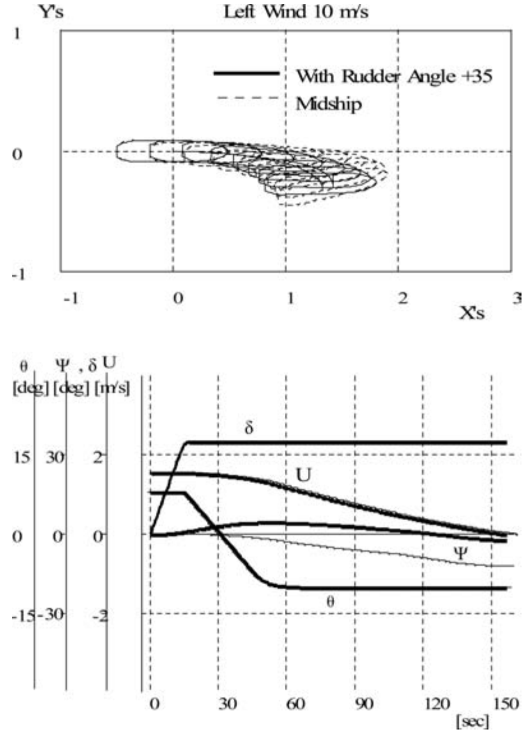


Figure 6. Example of controlling yaw moment by applying lee helm prior to reversing. (Left wind, 10 m/s).

to propeller reversing and performed the simulation test to confirm the effectiveness of proposed method.

Figure 6 shows the simulation results of the stopping manoeuvre where the propeller is put slow astern while proceeding at 3 knots under 10 m/s left wind. In the stopping manoeuvre with the rudder amidships, the test ship drifts leeward and turns her head into the wind. On the other hand, in the stopping manoeuvre that applies the maximum rudder angle steering to leeward prior to propeller reversing, although the test ship drifts leeward, the yaw moment can be reduced sufficiently and her original heading is well maintained.

4 APPLICATION OF PROPOSED METHODS TO IN-HARBOUR SHIP-HANDLING

4.1 *Anchoring under windy condition*

The series of ship-handling for anchoring consists of four simple manoeuvring elements, i.e. approaching, stopping, laying out anchor and fetching up. When approaching, it is necessary to proceed on the planned track and reduce the speed by the coasting manoeuvre. The proposed MHP operation is applicable for the coasting manoeuvre while approaching the anchorage especially under windy condition. When stopping for laying out anchor, it is essential to control the ships heading into the resultant of all external forces such as wind and current. The proposed steering control method can be applied to the manoeuvre to stop the ship while keeping her heading into the wind.

The authors applied the above two control methods to the actual anchoring of the test ship under the 7.5 m/s beam wind condition and the results are shown in Figure 7. During the approach ship-handling, the test ship first reduced her CPP blade angle from dead slow ahead to the MHP while proceeding at 4 knots for speed reduction and proceeded on the planned track by applying lee helm properly to control the head turning moment to windward. Next, when the headway was reduced to 3 knots, the test ship used hard-starboard steering to apply the maximum yaw moment to windward. After the yaw moment increased sufficiently, the test ship changed the blade angle to slow astern directly, skipping the propeller pitch zero operation. Finally, the test ship stopped with her heading into the wind and the chain was laid out adequately to leeward. The above results of the full-scale experiment indicate that the proposed methods can be effectively applied to anchoring under external forces.

4.2 *Crash stop astern manoeuvre in a harbour area*

The proposed steering control method during the stopping manoeuvre is applicable to the crash astern

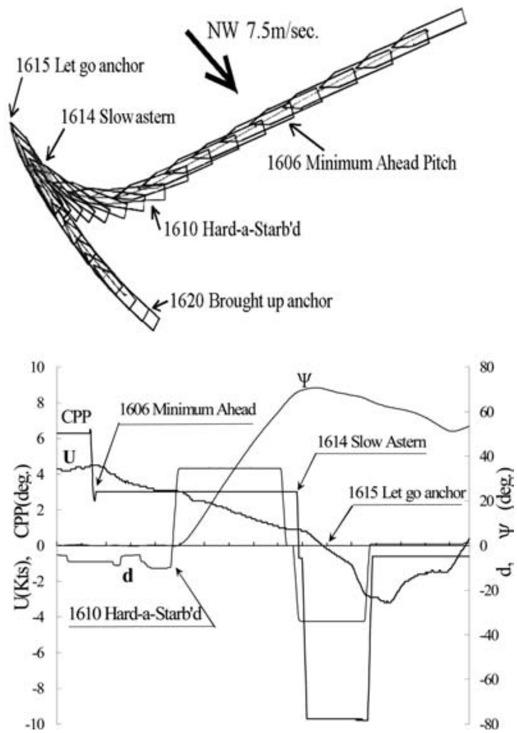


Figure 7. Effective CPP ship handling for anchoring in windy condition (Full scale trial).

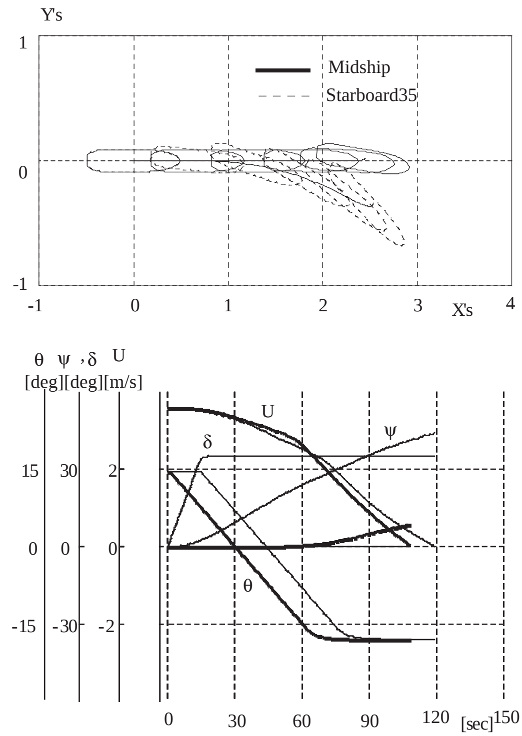


Figure 8. Example of the crash astern manoeuvre that applies maximum starboard rudder angle prior to the propeller reversing (Calm condition).

manoeuvre to avoid collision with other ships. In this case, it is necessary to stop the ship with the shortest distance by the propeller reverse operation and turn her head to the starboard as great as possible by the steering. To achieve this collision avoidance manoeuvre, the authors recommend the ship-handling method that puts the propeller to full astern after applying the starboard head turning moment by the maximum rudder angle steering and confirm the effectiveness of this method by simulation.

The results of the crash astern manoeuvre, while proceeding at 6 knots, that utilizes the maximum rudder angle steering to starboard prior to the full astern operation are shown in Figure 8. In the case of the crash astern manoeuvre with the rudder amidships, the test ship stopped turning her head slightly to the right of the original track, and both the head turning angle and the side reach are not enough to avoid collision. On the other hand, when the maximum starboard rudder angle was applied prior to the reverse operation, both sufficient starboard head turning angle and side reach to avoid collision were obtained. On this crash astern manoeuvre, although the 15 second delay in the reverse operation is observed compared to the manoeuvre with the rudder amidships, the head reach shows the same figure (2.5 L). This seems to be due to the additional resistance which is exerted by the steering and the oblique drift of the hull in the case of the manoeuvre with the maximum rudder angle steering. Therefore, it can be inferred that there is little effect of the reverse operation delay on the stopping distance in the proposed crash astern manoeuvre.

Next the authors performed a simulation study to confirm the effectiveness of the proposed crash astern manoeuvre under windy condition. The simulation was conducted with 10 m/s winds for various wind directions and the obtained results are shown in Figures 9–12.

In the case of the crash astern manoeuvre with the rudder amidships, the test ship stops almost on the original track with slight head turning, however the head turning angle is not sufficient for collision avoidance in the head-on situation. On the other hand, the crash astern manoeuvre with the maximum rudder angle steering, both sufficient side reach and head turning angle for collision avoidance are observed for each wind direction.

This simulation study demonstrates that the proposed crash astern manoeuvre is effective for collision avoidance under windy condition.

5 CONCLUSION

The authors performed full-scale experiments and a simulation study in order to develop an effective control method for CPP ships during the coasting

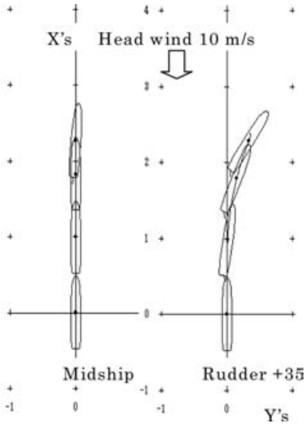


Figure 9. Crash astern manoeuvre with maximum starboard rudder angle (Head wind, 10 m/s).

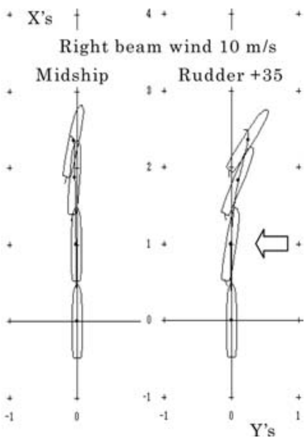


Figure 10. Crash astern manoeuvre with maximum starboard rudder angle (Right wind, 10 m/s).

manoeuvre and stopping manoeuvre. Results obtained in this study are summarized as follows.

(1) CPP ships under coasting using the MHP are controllable by steering, making it possible to keep the planned course.
(2) For ships with a single CPP and a single rudder, the MHP operation improves the manoeuvrability in coasting and in-harbour ship-handling.
(3) The unstable head turning motion of CPP ships during the stopping manoeuvre can be controlled sufficiently by the ship-handling method that applies turning motion to the ship by the maximum rudder angle steering prior to the reversing operation of the CPP.
(4) This ship-handling method is applicable to the ship-handling for anchoring under windy condition and the crash astern manoeuvre in a harbour area.
(5) Proposed steering control techniques are applicable and effective for the in-harbour ship-handling of CPP ships with forward accommodations such as the test ship. It remains to be seen whether these techniques are applicable for the ships with different configurations.

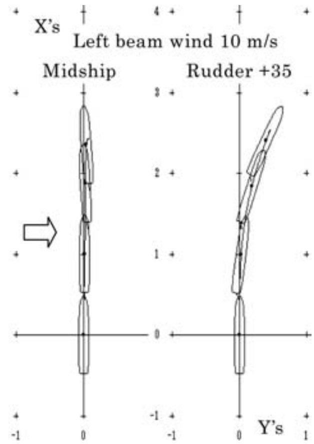


Figure 11. Crash astern manoeuvre with maximum starboard rudder angle (Left wind, 10 m/s).

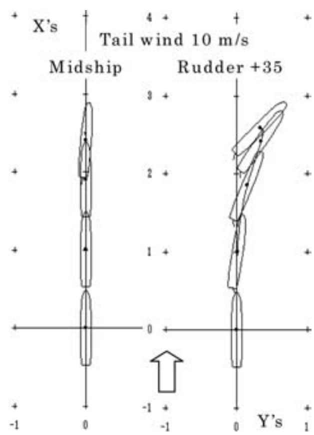


Figure 12. Crash astern manoeuvre with maximum starboard rudder angle (Tail wind, 10 m/s).

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

8.7 New Black Sea Terminal of port Kulevi and it navigating features

A. Gegenava, N. Varshanidze & G. Khaidarov
Batumi Maritime Academy, Batumi, Georgia

ABSTRACT: In May, 2007 in Georgia the new Black Sea Terminal (including the complex of a railway junction, capacities for storage of oil) was opened in the port Kulevi. Necessity of creation of the named terminal in Georgia was caused by following factors:

1. The necessity of search and the creation new alternative ways of safe transportation of oil to Europe;
2. A favourable geographical position of Georgia – Asia, the Near East and Europe crossroads;
3. Presence of already existed means of communication between Georgia and oil-producing regions – Kazakhstan, Turkmenistan and Azerbaijan.

Choosing the port and terminal place it was necessary to be guided first of all by maintenance of safety navigation and minimum expenses from the point of view of an economic profit. That is why the special attention was paid to search of a natural reservoir with an exit in the sea.

This article deals with the questions of construction of the oil terminal, maintenance of port Kulevi with means of the navigating aids and features of entering and leaving vessels.

1 INTRODUCTION

The idea of construction of the oil terminal came into view in 1998. The special attention was paid to search of a natural reservoir with an exit in the sea. After long debate the settlement Kulevi was chosen. By the end of 1998 survey and a preparatory works began. The works lasted for one year and in December 1999 construction works of the oil terminal and port Kulevi began.

The position of terminal is the river Khobi mouth, settlement Kulevi – Latitude 42.16 N & Longitude – 041.38 E, flowing into the sea on distance of 17 km from port Poti. The river Khobi flowing into Black sea between the rivers Enguri (15 km to the North) and Rioni (8 km to the South) (see fig. 1). The low coast between the rivers is bordered by shoal which is formed by carrying out of these rivers. The coast in the region of the river Khobi is low and sandy. The choice of the given place was caused by the following reasons:

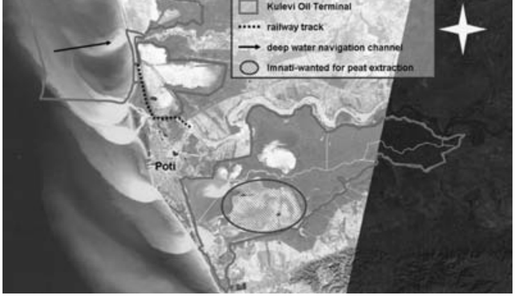

Figure 1. Location of Black Sea Terminal & Port Kulevi.

1 Presence of closely located powerful railway junction – Samtredia;
2 Presence of the big areas of free territories suitable for construction;
3 Presence of the developed infrastructure of a highway motorway;
4 Natural big depth of a mouth of the river Khobi – 6–9 meters;
5 Depths around the mouth of the river Khobi smoothly increase in process of removing from coast: 10 meters contour line passes in distance of 1.3 km from coast; 20 meters contour line – 2.5 km, and 30 – meters contour line – 3.2 km.
6 Possibility of an arrangement of moorings on the left bank of the river Khobi which in this area practically is not washed away, and also, possibility of creation of the entrance channel, direction of which, practically with the minimum expenses, coincides with a direction of a berthing line.

2 CONSTRUCTION OF THE OIL TERMINAL AND PORT KULEVI

The basic criteria at construction of the oil terminal and port were: taking into account the natural and climatic conditions for creation protected from excitement and sediments of aquatory with the least volume of dredging operations; preservation of the region's

Table 1. Types of tankers are processed with the terminal and port.

Deadweight (t)	100.000	40.000	28.700	17.100	7.600
Length Overall (m)	250.0	195.0	179.0	151.5	114.6
Breath Mounded (m)	42.2	28.0	25.3	22.4	16.5
Max. Draft Loaded (m)	15.0	12.2	11.0	8.7	6.0

ecosystem; construction of the oil terminal on handling and to storage of oil; construction of new port – Kulevi with a navigation channel; maintenance with the terminal and port processing of tankers given in table 1.

Construction of port and the terminal was simultaneously carried.

Territory of port occupied approximately 10 acre, and the terminal of 173 acre. In this territory the sea level from a chart datum on long-term supervision varies from 0.1 up to 1.0 meters. Because of a wave mode of the sea and prevention of flooding from the mouth of the river Khobi territories of port, the decision to raise safe height construction from a chart datum up to 2.5 meters it was accepted. In the beginning of construction approximately 11000 m^3 of the vegetative layer of a ground (sickness of 0.5 meter), was removed. For formation of the construction areas approximately 70000 m^3 of a sandy ground were covered. Dredging operations at the right coast of a mouth river Khobi and directly in aquatory of the future port were carried out with the help of dredgers and dredges allowing the increasing of the width of aquatory up to 290 meters. The design of a mooring facility of port was constructed in the following sequence: creation of an obverse wall by immersing of piles from metal grooves, marks LX-32, alternation 27 and 25 meter piles; immersing of piles from metal pipes diameter 820 mm on depth up to 25 meters in a unloading wall; immersing of piles from metal pipes diameter 1020 mm on depth up to 27 meters in anchor wall; dredging from pipes, using grab plant; installation channel frames in heads of piles from pipes with concreting; installation of an obverse distributive belt; dredging under anchor bar; stacking of wooden nozzles under anchor bar; installation anchor bar using the crane with their tension; concreting anchor beams; covering anchor bar a sandy ground with a layer not less than 1 meter; concreting head a mooring; dribble feed bosoms of a mooring up to a bottom of a final covering with level-by-level condensation; arrangement of a mooring after the end of dredging operations at a mooring and in water area of port.

As a result of the made construction the new oil terminal and port Kulevi consists of:

- The oil terminal on handling and to storage of oil distributed in 16 shore tanks, each in volume of 20000 m^3 (see fig. 2);
- A complex of hydraulic engineering constructions providing unloading of oil from railway or road transport to shore tanks, communication with objects of a tank farm, transportation of oil to moorings and their loading on tankers;

Figure 2. Shore tanks of oil terminal.

Figure 3. Hydraulic engineering constructions.

Figure 4. Hydraulic engineering constructions.

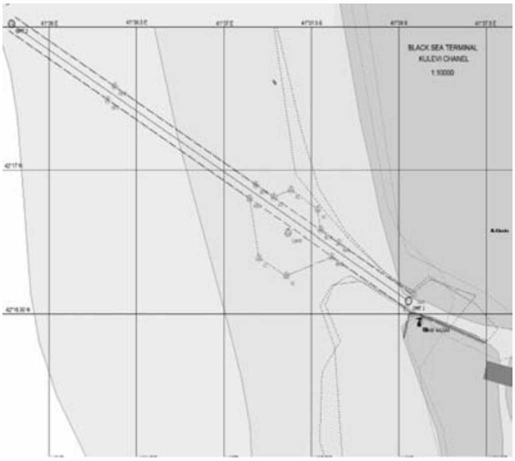

Figure 5. Navigation channel.

– Hydraulic engineering constructions, which consist of: mooring No. 1 for reception of vessels by deadweight 100000 T., mooring No. 2 for reception of vessels by deadweight 40000 T. and mooring No. 3 for vessels of auxiliary fleet (see fig. 3, 4);
– A navigation channel, including: the entrance channel, manoeuvring space – swinging room (swinging pool) and operational space at moorings (see fig. 5).

3 NAVIGATING PROVISION OF PORT KULEVI

3.1 *ORT Kulevi*

Port Kulevi (42°16′N, 041°38′E) is located in the mouth of the river Khobi, the settlement Kulevi, running into the sea on distance of 17 km to the North from port Poti.

Depths in mouth sites of the rivers Enguri, Khobi and Rioni are changeable because of moving sediments and constant sea stream directed from the South on the North up to 0.4–0.6 knots.

Grounds in a coastal zone up to contour line 10 m – silt with fine sand, in sea zone – dense silt with fine sand, clay, a broken shell.

Fogs in area of a mouth of the river Khobi – 29 days with fogs on the average per year.

Visibility is mainly good. Visibility range more than 5 miles is observed in 90% of cases. In 65% of cases visibility range about 10 miles – transmissivity of atmosphere $T = 0.74$.

The entering channel begins on natural depths and proceeds up to a mooring No. 1. Length of the channel – 2.3 miles, width in a bottom – 210 m, estimated depth – 18,2 m.

The manoeuvring space is used for a swinging. Diameter swinging room (swinging pool) – 500 m, which is settled on the distance of 800 m from a mooring No. 1.

Operational space meets the conditions of safe manoeuvring of vessels in narrow pools with a one-way location of moorings. The width of operational space is – 230 m.

Moorings – No. 1 for reception of vessels by deadweight 100000 T., No. 2 for reception of vessels by deadweight 40000 T. and No. 3 for vessels of auxiliary.

Anchorages – the area No. 200 is located on outer roads of port Poti, in distance of 5 miles on the South from a mouth of the river Khobi.

The western part of this area with depths from 20 up to 90 m is suitable for anchorage tankers with draft up to 15 m.

Pilot – Compulsory. Vessels expect pilotage in area of No. 200. With the help of VTS operator the pilot meets a vessel at receiving buoy (OMT2) in 2.3 miles to NW from an extremity of a mooring No. 1. Communication with operator VTS and the pilot is carried out on VHF, the channel 73.

Aids of navigation provide navigation of vessels on the entering channel in the daytime. Navigating orientation is carried out with the help of complex use of coastal and floating aids of navigation. The entering channel is equipped with sector light beacon – PEL-6-10D, fixed on an axis of the channel and a floating protecting buoy, exposed on outer limit of fairway on Lateral System (IALA) – Region A «red to port side». Swinging pool and the deep space of port are protected special buoys.

Navigation regime in the zone of responsibility of Georgia is performed in accordance with recommended routes, which are indicated on the charts and pilot books. Recommended track from the port of Kulevi to the port of Poti navigation should be carried out in accordance with two-way recommended track, the separate line of which is laid through the recommended two-way track No. 02 (see table 2).

3.2 *VTS – Navi Harbour of port Kulevi*

For provision of complex system of safety of navigation of tankers on the channel and to moorings of the terminal, VTS – NAVI HARBOUR of port Kulevi was created, including the following equipment and elements (see fig. 6):

– Radar station – Bridge Master-E with the radar processor;
– The registrar VHF VTS Audio;
– Server reference data VTS (VTS Information System);
– Server VTS;
– The equipment of operator VTS – Monitor TFT 24", the PC of the workstation, the specialized keyboard of operator VTS, Software operators display module Navi Harbour (see fig. 7);
– System of TV observation VTS consisting of – CCTV camcorder VTS of 120 mm, with rotator and control panel, TV monitor TFT 20", observation registrar (CCTV) (see fig. 8);
– Base station DGPS Trimble DCM232;
– Base station Transas Redundant UAIS;

– VHF VTS – ICOM-M602 and ICOM-A110 for communication with aircrafts;
– Coastal station GMDSS A1 – 16/70 channel – 2x RT4160, DSC modem T500.

Recommended tracks pass in distance 8–10 miles from coast and there are no navigating dangers near them. According to Resolution IMO A.529 the area of navigation is related to a voyage stage – “approaches

Table 2. Recommended two-way track from the port of Kulevi to the port of Poti.

Name of the point	Coordinates of the points		Direction of the way between the points	Nautical miles
	Latitude N	Longitude E		
K01	$\varphi = 42°\ 18.78'$N	$\lambda = 041°\ 32.97'$E	186-06	4,2
P01	$\varphi = 42°\ 14.63'$N	$\lambda = 041°\ 32.36'$E		

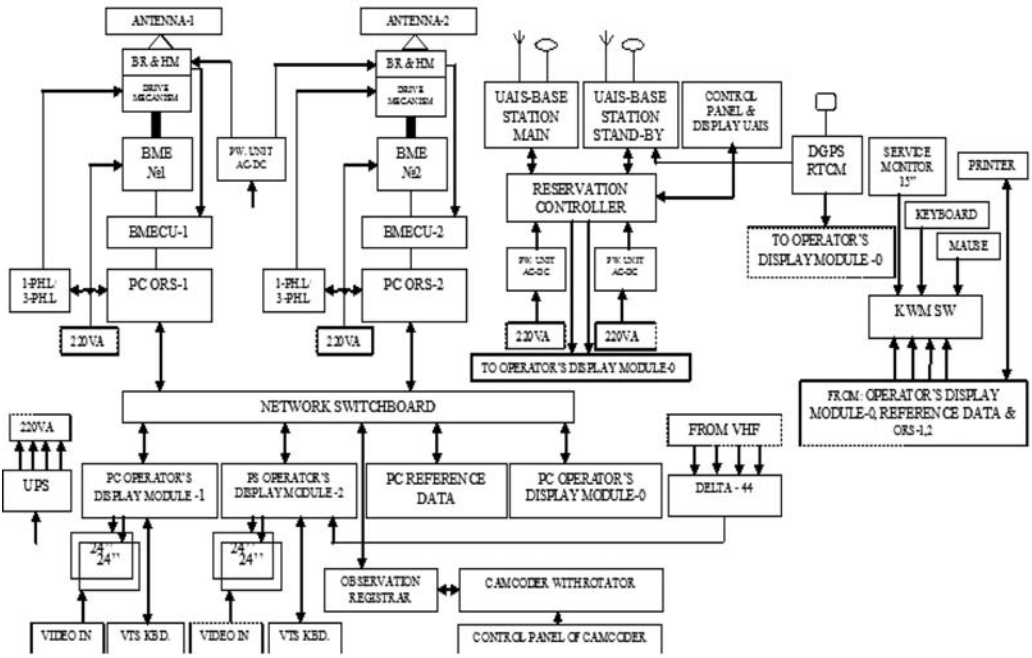

Figure 6. The bloc scheme VTS-Navi Harbour Port Kulevi.

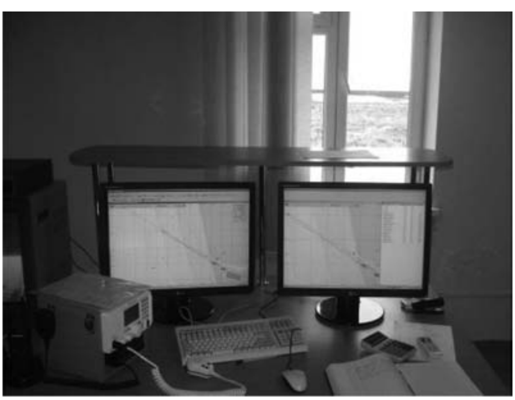

Figure 7. Workstation of operator VTS.

Figure 8. System of TV observation VTS.

to ports". Under the calculations and the analysis of the received indicators carried out for, the following conclusion was made for recommended entering tracks: the visual navigation aids do not provide necessary accuracy of position fixing during navigation on the channel. Necessary accuracy of position fixing is possible only by using sector leading light, floating navigating protections and VTS – NAVI HARBOUR.

3.3 *Analysis of hydrometeorological conditions*

The analysis of hydrometeorological characteristics showed, that the limiting factor, influencing on the safety of navigation and effective operation of hydraulic engineering constructions of port Kulevi, is the excitement arising mainly at action of winds of the westerly.

Thus, at an initial stage wind conditions of the given area were carefully analyzed.

The analysis of wind conditions showed, that the basic wave creating winds are winds of the westerly. The winds of easterly are coastal and do not render essential influence on a wave situation (see fig. 9).

The most dangerous, from the point of view of safety of navigation, are winds of the western and southwest directions due to the big dispersal of waves (see table 3). At moderate and rough sea on approaches to a mouth of the river Khobi the tied rip is formed. At rough sea in a mouth of the river it is observed tyagun.

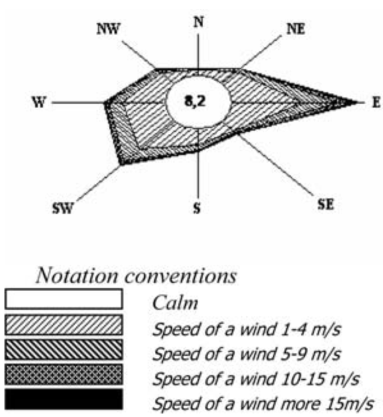

Figure 9. Annual wind rose.

4 FEATURES OF ENTRANCE AND EXIT OF VESSELS TO PORT KULEVI

In-coming channel of port Kulevi has the following data: length – 2.3 miles;

Distance from receiving buoy up to swinging pool – 1.2 miles; diameter swinging pool – 500 meters; distance from the centre swinging pool up to an entrance to port – 5.7 cables.

For a safe entrance and exit of vessels at least 3 tows are used.

The entrance is carried out on a technological card of enter and mooring (see fig. 10):

- Entering vessel accepts the pilot at receiving buoy (OMT2) and under supervision of operator VTS begins to move on an axis of the channel with maximum critical speed of 4–5 knots.
- For fast repayment of headway of a vessel, during its move to swinging pool to pass stern towing line on a tug.
- On arrival of a vessel to the swinging pool its inertia decreases, and turn of a vessel begins through the starboard (position 1, 2) with the help of two tugs and bow thruster (if those are at entering vessel).
- A vessel is swinging 180° (position 3, 4), then the stern tug starts to tighten a vessel to stern in a direction to a mooring (a position 5).

The exit of a vessel is carried out without any difficulties as a vessel stands bow outward at a mooring.

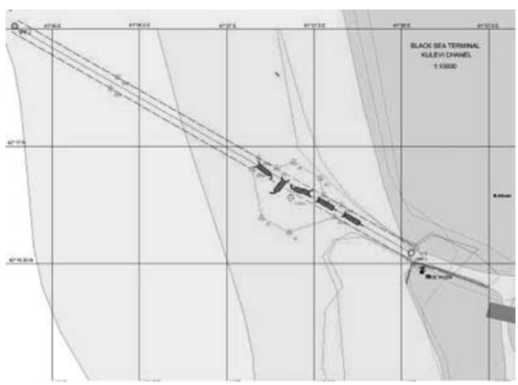

Figure 10. Technological card of enter and mooring tankers of Kulevi port.

Table 3. Wind directions & speed in harbourage of Kulevi port.

Speed of a wind m/s	Direction										Total
	–	N	NE	E	SE		S	SW	W	NW	
Calm	8.2	–	–	–	–		–	–	–	–	8.2
1–4	–	1.7	5.0	17.3	4.2	4.6	12.2	10.4	4.5	59.9	
5–9	–	0.3	1.1	8.7	0.9	1.8	5.3	3.4	1.3	22.8	
10–15	–	0.1	3.4	0.1	0.5	1.1	0.9	0.3	6.4		
More 15	–	0.1	1.9	–	0.1	0.2	0.3	0.1	2.7		
Total	8.2	2.0	6.3	31.3	5.2	7.0	18.8	15.0	6.2	100	

It is necessary to make small efforts from the bow and stern to withdraw a vessel using tugs from a mooring and it immediately appears on a channel axis and in its own power exits outward moving on the channel to receiving buoy under the direction of the pilot and operator VTS.

5 CONCLUSIONS

It is possible conclude, that prospect of development of port Kulevi from the point of view of safety navigation, its economic feasibility and also effective operation of hydraulic engineering:

– In connection with that buoys, bordering width of the channel are established on depths of 8–12 meters, and their anchor cables length is 30 meters. They drift under the influence of current, the width of the channel varies and a basis of safe movement of a vessel in the channel is orientation with help VTS – NAVI HARBOUR.
– In area of port Kulevi dynamics of the sediments is caused, basically, a firm drains of the river
– Khobi. The basic sedimentation of deposits occurs on internal water area, and also on a site entering channel in 0–700 meters, that is why it is necessary to carry out measurements of depths per 2 weeks and after each storm.
– The most dangerous, from the point of view of safety of navigation, are a wind of the western and southwest directions. It is expedient to carry out the complex analysis of hydrometeorological characteristics in area of port Kulevi with the purpose of development of an optimum variant of the protective constructions, allowing to increase a degree of navigating safety at navigation on water area, and also to increase efficiency of its operation.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

8.8
Analysis of the influence of current on the manoeuvres of the turning of the ship on the ports turning-basins

J. Kornacki
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: The paper presents the problem of the influence of current on ship during the manoeuvre of the turning and influence on this manoeuvre. The test of the different qualification of the influence of current on the manoeuvre of the turning of the ship was undertaken. The analysis of the influence of the current was conducted on this manoeuvre.

1 INTRODUCTION

1.1 *The turning basins*

Can be understood as a two different meanings. First as the manoeuvring area appointed by the ships. Second as the hydro-technical building artificial or natural with suitable horizontal and vertical dimensions, where the considerable alterations of the course of the ship are executed.

The manoeuvre of ships turning is one of the often port manoeuvres. The ships turning is executed every time during the ships port call. Simultaneously, it is comparatively little examined. We know that the influence on the size of turning basin during the manoeuvre have the large quantity of factors.

The turnings of the ships are practices "in the place". This should be understand as the change of the course of the ship whose linear speeds, during the manoeuvre, are close to zero. Turning the ship over is done on the turning basin as a result of the planned tactics of manoeuvring and can be done on itself or in co-operation with tugs or use of anchors or spring.

Turning basins are areas appointed and the reservoirs not appointed on which the turn of the ship is executed with the considerable value of the course and they are a part of channels or port basins. Certainly due to safety, the turning basin as the hydro technical building always has to be larger in all dimensions than the manoeuvre area to avoid the collision with bottom or bank (Kornacki & Galor 2007).

1.2 *Designing of turning basins*

Two methods of defining their dimensions can be use. Those are analytic method and simulating method (Kornacki, 2007).

Analytic method is the very simplified. Turning basins are divided on two groups. First group establish non-currents turning basins. Second group establish turning basins on currents waters. It is premised that the turn of the ship is described by the circular area and in the case of currents waters, the area is described by the shape similar to figures definite by two semicircle and two straight lines joining them – the stretched wheel similar to ellipse. The depth of water on the turning basins is defined in dependence from loading status of turned over ships (Kornacki, 2007; Dz.U.98.101.645).

The dimension of the turning basin on the non-current waters defines the equation 1 (Gucma & Jagniszczak, 2006; McCartney, 2005):

$$d_o = 1.5L_{OA} \tag{1}$$

The dimensions of turning basins on the current waters define the equations 2, 3 (Gucma & Jagniszczak, 2006; McCartney, 2005):

$$l_o = 1.5L_{OA} + v_c t_o \tag{2}$$

$$b_o = 1.5L_{OA} \tag{3}$$

The simulating method of designing the parameters of turning basins are based on series of tests in comparable conditions on prepared model of reservoir and the model of the ship planned to use the turning basin. The results of tests are subjected the statistical processing. Effect of that kind of research is delimitation of the area of manoeuvring on the turning basin according to the various foundations of hydro meteorological conditions, various parameters of ships and various levels of the trust. Characteristic feature of the simulating method is that simulating models of the ship manoeuvring are especially designed to the solved problem (Guziewicz & Ślączka, 1997; The unpublished report 1995; The unpublished report 2000).

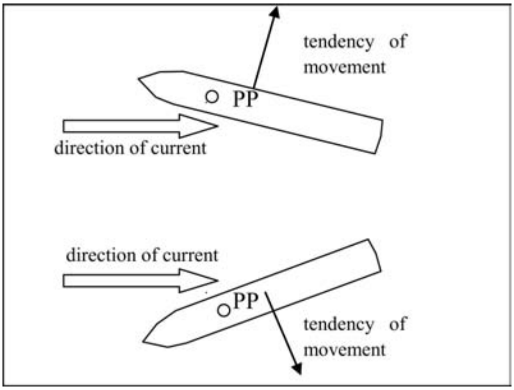

Figure 1. The tendency of the stopped ship movement with opposite current.

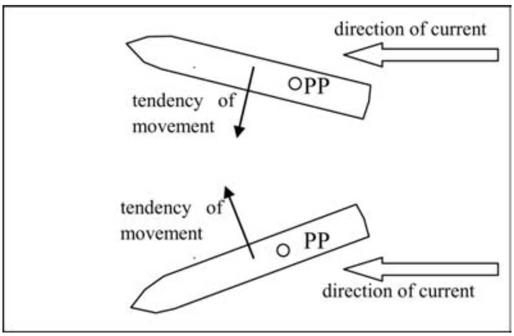

Figure 2. The tendency of the stopped ship movement with current.

2 CURRENTS INFLUENCE

A feature of any river manoeuvres is the current. It is common for a river berth to lie in the same direction as the prevailing current so that the current can assist with turning and berthing. In this case, a turning can be done with a current or opposite a current.

Opposite current give the advantage of relatively high speed through the water with a reduced speed over the ground. Consequently, steerage at low ground speed is improved by the good water flow over the rudder. The ship will be easier to stop.

Certainly, manoeuvring with a current give completely different situation. High speed over the ground may mean low speed through the water. It is necessary to take care of ground speed all the time.

Below figure show the tendency of the stopped ship movement.

We should note that currents are usually complex, with varying rates and directions that can change hourly. Local knowledge is essential for safe navigation. A ship making headway into a current, but stopped over the ground, will have a forward pivot point.

The influence on manoeuvring is serious for even weak currents like ½ knots. It depends of the ship

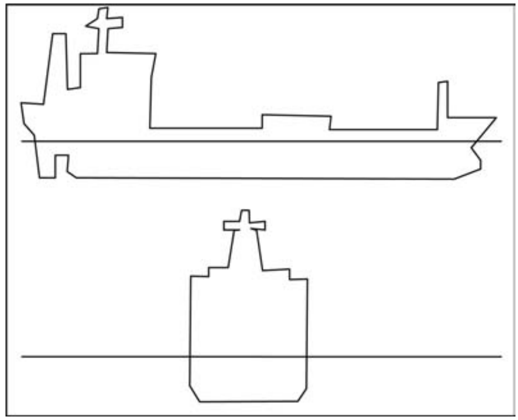

Figure 3. The lateral and longitudinal ships area with wet surface.

type and the objectives of manoeuvring in a smaller extent than in case of strong wind. On restricted water area everything is fine as long as manoeuvring ship remains under a speed of a few knots and the current is not so strong. The situation can be worst in case of dynamic positioning or low speed manoeuvring like ship's turning.

The ship outline is demonstrated in Figure 2.

The ship manoeuvring motion equations are as follows (Artyszuk 2002):

$$\begin{cases} (m+m_{11})\dfrac{dv_x}{dt} - (m+m_{22})v_y\omega_z = F_x \\ (m+m_{22})\dfrac{dv_y}{dt} + (m+m_{11})v_x\omega_z = F_y \\ (J_{zz}+m_{66})\dfrac{d\omega_z}{dt} + (m_{22}-m_{11})v_x v_y = M_{Az} \end{cases} \tag{4}$$

The influence of current is a part of hull forces, which are a part of:

$$\begin{cases} F_x = F_{xH} + F_{xP} + F_{xR} + F_{xA} \\ F_y = F_{yH} + F_{yP} + F_{yR} + F_{yA} \\ M_{Az} = M_{AzH} + M_{AzP} + M_{AzR} + M_{AzA} \end{cases} \tag{5}$$

Hull forces can be shown:

$$F_H = 0.5\rho L T v_{xy}^2 c_{fh}\left(\beta, \overline{\omega_z}, \frac{h}{T}, \frac{b}{B}\right) \tag{6}$$

3 ANALYSIS OF CURRENT EFFECT DURING SHIPS TURNING TRIALS

Tests of ships turning are based on chemical tanker model. The ship data is summarised in Tab. 1 (Artyszuk 2005).

The analysis of the current effect during ships turning on the turning basin is based on the series of turning-tests. The tests were executed in the wide port

Table 1. Ships model data.

TYPE: chemical tanker	
L_{OA}	103.6 [m]
L_{BP}	97.4 [m]
B_M	16.6 [m]
T_M	7.1 [m]
H	9.4 [m]
H_A	35.2 [m]

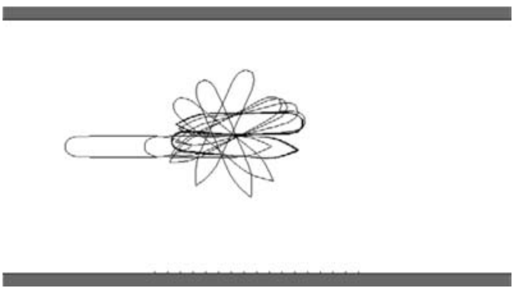

Figure 4. The turning manoeuvre without current – ship shapes in time of commands.

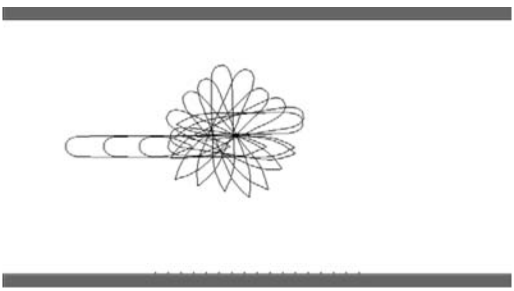

Figure 5. The turning manoeuvre without current – ship shapes in every 30s.

channel in various current conditions. Tests were executed apply the model of the ship mentioned above chemical-tanker, without the use of tugboats, with own propulsion, standard 35 degrees rudder and thrusters (Artyszuk 2005). Port channel had the width of the quadruple of the length of the ship and had not the influence on the area of manoeuvring. The tests were begun from the same places and interrupt after turn over ship to final course 270°.

3.1 *Turning manoeuvres without current*

First, for the comparison, the series of tests was conducted without current. All tests were in same environmental condition. It means: shallow water, slow speed, no wind, starboard and port turning and usage of ruder, main propulsion (ahead/astern) and bow thruster if necessary. Results are introduced below.

Figure 4 and 5 present typical turning manoeuvre with starboard turn without current. Below are present manoeuvring areas on turning basin (Fig. 6) and comparison with analytic method (Fig. 7).

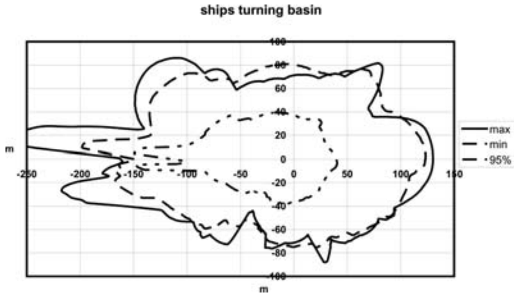

Figure 6. The manoeuvring areas on turning basin without current.

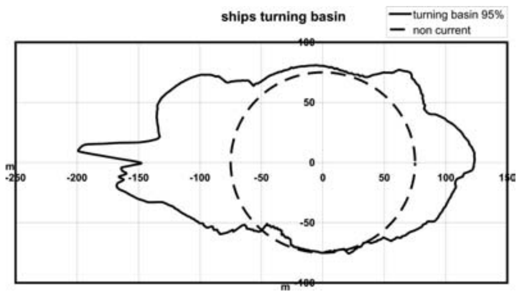

Figure 7. The manoeuvring areas on turning basin without current compared with analytic method.

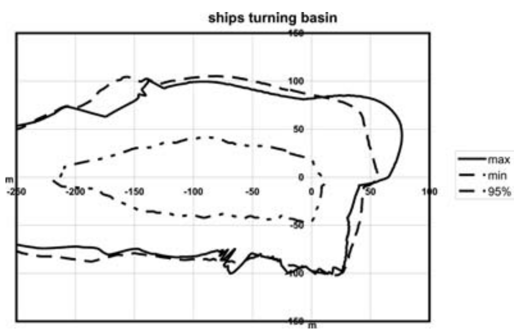

Figure 8. The manoeuvring areas on turning basin with opposite current.

Results base on series of 30 tests.

3.2 *Turning manoeuvres with opposite current*

All tests were in same environmental condition as without current (shallow water, slow speed, no wind, starboard and port turning and usage of ruder, main propulsion and bow thruster). Similar as before 30 tests were conducted. Current had 2 knots and direction 270°. Results are introduced below.

Figure 8 presents manoeuvring areas on turning basin with opposite current. In all cases tests were conducted as much as possible around beginning of co-ordinates. Figure 9 presents comparison results of analytic method and simulating method.

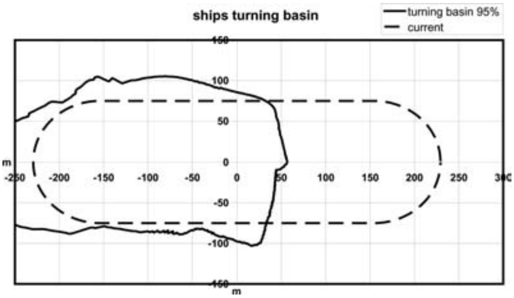

Figure 9. The manoeuvring areas on turning basin with opposite current compared with analytic method.

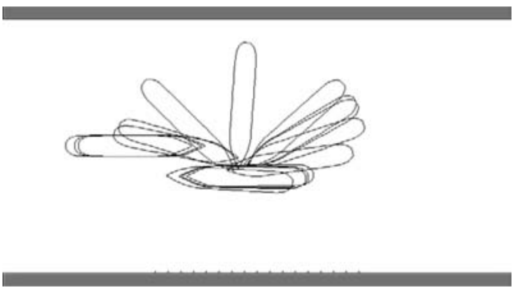

Figure 10. The turning manoeuvre, starboard turn, with current 090° and 2 knots – ship shapes in time of commands.

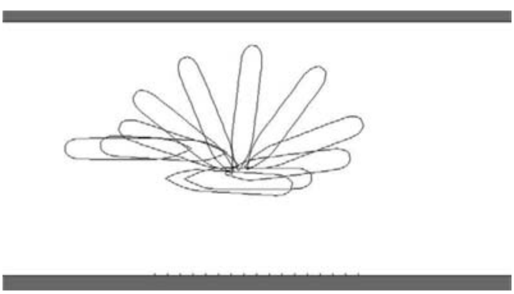

Figure 11. The turning manoeuvre, starboard turn, with current 090° and 2 knots – ship shapes in every 30s.

3.3 *Turning manoeuvres with current*

During tests of turning manoeuvres with current, similar like before, all environmental conditions stay the same. Current had 2 knots and direction 090°.

First, the shapes of typical tests are presented.

Next, manoeuvring areas on turning basin with current are presents (Fig. 14).

Comparison of results of analytic method and simulating method is presented below.

3.4 *Comparison of turning manoeuvres in different current conditions*

It was interesting what differences are between the various tests groups of the manoeuvres of the turning of the ship. One can observe differences in manoeuvring

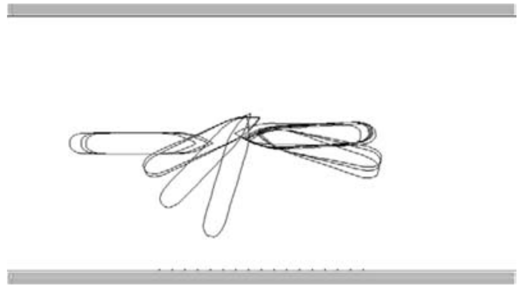

Figure 12. The turning manoeuvre, portside turn, with current 090° and 2 knots – ship shapes in time of commands.

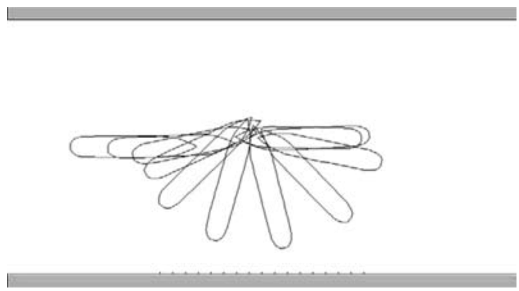

Figure 13. The turning manoeuvre, portside turn, with current 090° and 2 knots – ship shapes in every 30s.

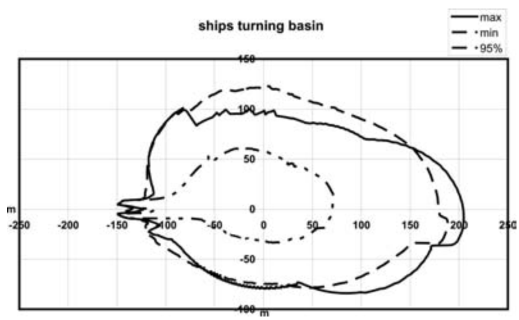

Figure 14. The manoeuvring areas on turning basin with current.

areas appointed for various current conditions. But, if the influence of the current on different elements for this hides.

The comparison of the profile of yow velocity was introduced in dependence from the course of the ship for three typical current situations below.

It is easily to notice that there are no considerable differences in the course between individual situations. One can qualify the phase of the growth of the yow velocity, then the period of changing course in dependence from the tactics of the manoeuvre with the possible to the qualification maximum, and finally the phase of slowing down the yow velocity in the aim of the position of the ship on the new course.

You can not also see the considerable difference of period of executing manoeuvres.

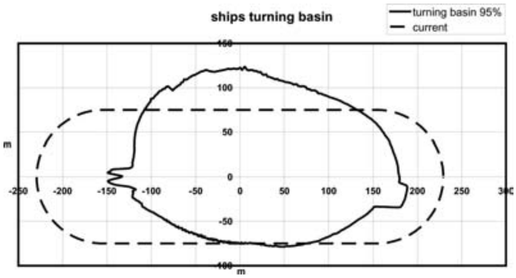

Figure 15. The manoeuvring areas on turning basin with current compared with analytic method.

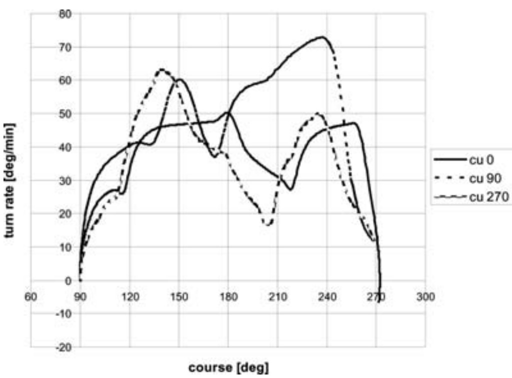

Figure 16. Turning rate [deg/min] on different tests groups.

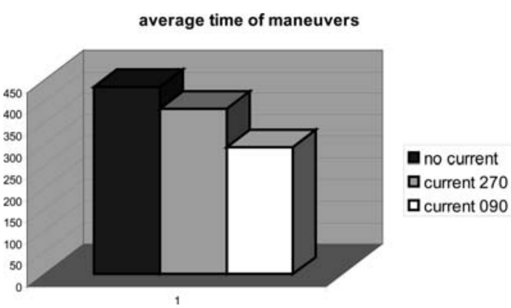

Figure 17. Average time of manoeuvres on different tests groups.

The differences what can be observe they are the result of hurry during the executing of the manoeuvre rather, in the aim his of the safe realization.

3.5 *Work of current*

Looking on the manoeuvring areas of individual groups, you can see that current has the influence not only on the growth of the dimension in the axis of the working of the current but he also influences growth of width of such area. We observe the differences in width of manoeuvring areas of grade ten percent of the width of the manoeuvring area without current. Accepting the steady working of the current, it can be:

$$\begin{cases} F_H = 0.5\rho L_{BP} T_M v_{xy}^2 c_{fh}\left(\beta, \overline{\omega_z}, \dfrac{h}{T}, \dfrac{b}{B}\right) \\ W_C = F_H s_C \end{cases} \tag{7}$$

Working of the current can be understood as the kinetic energy causing position offset.

4 CONCLUSIONS

According to the above examinations some general points could be formulated.

The manoeuvring area is not complaint with this appointed by the analytic method.

It was observed, larger from foreseen, the extension of the size of the turning basin upon the width.

It was observed, smaller from foreseen, the extension of the size of the turning basin upon the length.

The current does not have the significant influence on stepping out yow velocity and the time of the manoeuvre. However certain influence has on accelerations, what joins with the occurrence of additional strengths on the hull and different moving the ship causes.

The ship on the current behaves like the wing and not as the inert object moving oneself together with the surrounding her environment. It joins with the use of ships drive propulsions obviously, and occurrence on the hull of the suction side and the pressure side.

One can apply the work of the current on the hulk to the qualification of the sizes of the turning basin while manoeuvring on the current.

5 SYMBOLS AND UNITS

b_o – width of the turning basin [m],
B_M – moulded breadth [m],
β – drift angel [°],
$c_{fxC}, c_{fyC}, c_{mzC}$ – hall coefficients [–], [–], [–],
d_o – diameter of the turning basin [m],
F_x, F_y, M_{Az} – external total surge, sway forces and yaw moment [N], [N], [Nm],
h – depth [m],
H_A – air draught from the keel [m],
L_{BP} – length between perpendiculars [m],
L_{OA} – length over all [m],
l_o – length of the turning basin [m],
m, J_{zz} – mass and inertia moment [kg], [kg m^2],
m_{11}, m_{22}, m_{66} – virtual masses [kg], [kg], [kg m^2],
s_C – length ship track to final position offset [m],
T_M – draught [m],
t_o – time of the turning [s],
v_c – speed of the current [m/s],
v_d – drifting speed [m/s],
v_x, v_y, ω_z – surge, sway and yaw velocity [m/s], [m/s], [1/s],

ρ – water density [kg/m^3],
W_C – work of wind [J],
H, *P*, *R*, *A* – subscripts indicating respectively: hull, propeller, rudder or wind

ACKNOWLEDGEMENTS

I would like to thank Jaroslaw Artyszuk for the facility of the application of the simulation of manoeuvring the ship to scientific of aims.

Some part of tests was executed using the Ship-handling Simulator.

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Chapter 9. Sea-river and inland navigation

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

9.1 Satellite and terrestrial radionavigation systems on European inland waterways

J. Januszewski
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The usefulness for all sea users of Satellite Navigation Systems (SNS), Satellite Based Augmentation Systems (SBAS) and Automatic Identification System (AIS) is well known. The possibility, actual and future, of the utilization of all these systems on European inland waterways, GPS augmented by IALA DGPS reference stations, GPS augmented by European SBAS – EGNOS from direct Signal–in–Space (SIS) and GPS augmented by EGNOS from re–transmission over AIS, is presented in this paper. The operational systems, such as the German network IALA DGPS and DoRIS, and planned system such as GALEWAT, MARGAL, MUTIS and MARUSE are described also.

1 INTRODUCTION

The European Union recognises the great potential of inland navigation as an alternative transport mode for freight transport. Facing tremendous capacity and environmental problems in the land transport modes, in particular road transport, the European transport policy consequently has a great interest in developing inland waterway transport to become a real alternative whilst keeping the environmental burden to a minimum [www.iris-europe.net].

The continuous information of user's position is one of the most important factors, which determines the safety of the user in the transport, on inland waterways also. The requirements towards radionavigation are well defined for the maritime world (sea navigation, coastal navigation etc.) in the IMO (International Maritime Organization) resolution A.915(22). As the IMO is not responsible for inland waterways, and these requirements are not binding, the new performance requirements must be created. The most comprehensive approach for the inland navigation community is the project MARUSE. For traffic management and information the following requirements have been identified: absolute accuracy – 3 m, alert limit – 7.5 m, time to alarm – 10 s, integrity risk (per 3 hours) – 10^{-5}, availability (% per 30 days) – 99.8, continuity (%/3hours) – 99.97 [Amlacher et al. 2007]. The accuracy requirement of 3 m has been confirmed in real time operations, e.g. for the matching of the radar image with the Electronic Navigation Chart (ENC).

Moreover the coordinates of actual position must be sent to other ship's devices and different kind of land stations. That's why the user's position on inland waterways must be fixed continuously by specialized electronic position–fixing systems – satellite navigation systems (SNS), the differential mode of these systems, satellite based augmentation systems (SBAS) and terrestrial radionavigation systems [Januszewski J. 2007].

2 SATELLITE NAVIGATION SYSTEMS AND THEIR DIFFERENTIAL MODE

A presently (December 2008) unique, fully operational and global system is the American GPS (Global Positioning System – Navstar) and its differential mode DGPS. Experience has shown that stand alone GPS system does not provide sufficient accuracy for a reliable operation of the system. Many maritime administrations have implemented a DGPS service in their waters to improve safety and efficiency of navigation [Hoppe M. et al. 2005]. At present more than 300 DGPS reference stations have operational status; and this number is still increasing [ALRS 2008/09]. In this paper these stations are called IALA DGPS.

For maritime users (channel and coastal navigation, harbour approach) the IALA DGPS stations are situated at seashore, for inland navigation the additional stations must be installed inland in properly chosen places.

The provision of DGPS corrections can be realized in two different ways:

- IALA DGPS network covering all inland waterways of the chosen region or the territory of the country,
- the distribution of the DGPS corrections via AIS base stations.

The first solution became realized in Germany. The two IALA DGPS stations were located in Helgoland and in Gross Mohrdorf, which cover the German Bight and the German part of the Baltic Sea, respectively. These stations and the third, planned in Zeven, will provide good coverage of the harbour entrances of the great three German rivers – Elbe, Ems and Weser.

Table 1. Distribution (in per cent) of satellite elevation angles (H) in open area for Galileo system (GAL) and GPS system (GPS) at different observer's latitudes (φ).

		Elevation angle H [°]								
φ [°]	System	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90
40–50	GAL	23.0	16.7	14.3	11.8	9.9	8.5	7.6	6.1	2.1
	GPS	22.2	16.9	14.9	12.1	10.1	8.7	7.2	5.8	2.1
50–60	GAL	23.0	19.7	14.5	11.8	9.3	8.2	6.4	4.8	2.3
	GPS	24.1	19.3	14.8	11.3	10.1	7.8	6.1	4.1	2.4

This IALA DGPS stations network became extended for four stations – Bad Abbach (Bavaria), Iffezheim (Baden-Württemberg), Koblenz (Rhinelad-Palatinate) and Mauken (Sachsen-Anhalt), which permitted coverage for all of Germany. The range of these stations over land is approximately 250 km [Hoppe M. et al. 2005].

The second solution became realized in Austria, via the DoRIS (Donau River Information Services) system. 23 DoRIS base stations are installed along the Danube, two of them are augmented with DGPS functionality and distribute the corrections over the neighbouring base stations to the users onboard ships. The distribution of these two stations, called AIS DGPS, is such that the distance between the user and the nearest DoRIS station is less than 90 km always. The AIS DGPS stations produce the AIS message type 17, according to the ITU–R M.1371–1 standard, which includes the DGPS correction data. Over the AIS radio data channel this message is broadcast every 10 seconds. The DoRIS system has been operational since 2006 year with no major outages.

Nowadays the GLONASS (Russian system) cannot be a continuous position fixing system (the number of operational satellites is less than nominal 24 continually). The new system – Galileo, sponsored by the European Union, is under construction as the European contribution to the next generation of satellite navigation [Spaans J. 2008], but these two systems are already taken into account, in this paper also. The new navigation satellite system (NSS) actually built by China, called Compass, was not taken into account.

The number of satellite (ls) which can be used for to fix ship's position first of all depends on masking elevation angle H_{min} of the receiver and the number of satellites fully operational at given moment. If the angle H_{min} increases, the number ls decreases. As the most important European inland waterways are at geographical latitudes 40–60° N, we can pose the question – what is or what will be the geometry (elevation angle and satellite azimuth, in particular) of two the most important SNSs – GPS and Galileo in this part of Europe.

The distribution (in per cent) of satellite elevation angles (H) in two latitude zones, 40–50° N and 50–60° N (containing mentioned above waterways) for both systems is presented in the Table 1. We recapitulate that:

- the distributions of angle H values in all zones for both systems are practically the same,
- for both systems in all zones about half of satellites are visible below 30°, while the percentage of satellites visible above 70° is less than 10.

The distribution (in per cent) of satellite azimuths for masking angle $H_{min} = 0°$, $H_{min} = 5°$ and $H_{min} = 15°$ for both systems at different observer's latitudes is shown in the Table 2. We can say:

- distributions of satellite azimuths for both systems are practically the same at given angle H_{min},
- the number of satellites in different azimuth's intervals depends on the observer's latitudes for both systems,
- at latitudes 40° to 60°, independently of H_{min}, the number of satellites with azimuth from interval 315–045° are for both systems less than from intervals 045–090° and 270–315° considerably.

It means that position accuracy depends on river or canal orientation and the form of shoreline. The distributions in the tables 1 and 2 are the results of the calculations made by using author's simulating program. The detailed results were presented among other things in [Januszewski J. 2004] and [Januszewski J. 2005].

Nowadays on inland waterways the 3D position nevertheless can be obtained in almost all cases, because the GPS spatial segment consists of 31 satellites fully operational.

3 SATELLITE BASED AUGMENTATION SYSTEMS

The Satellite Based Augmentation Systems (SBAS) as Wide Area Augmentation System (WAAS), Multifunctional Transport Satellite Based Augmentation System (MSAS) and European Geostationary Navigation Overlay System (EGNOS) are adequately accessible in USA, Canada, Japan and Europe [Prasad R., Ruggieri M. 2005]. The C/A codes used by all these systems belong to the same family of 1,023-bit Gold

Table 2. Distribution (in per cent) of satellite azimuths for different masking elevation angles (H_{min}) for Galileo system (GAL) and GPS system (GPS) at different observer's latitudes (φ).

			Satellite azimuth H [°]							
φ [°]	H_{min}[°]	System	0–45	45–90	90–135	135–180	180–225	225–270	270–315	315–360
40–50	0	GAL	8.7	19.5	11.1	10.8	11.1	11.1	19.0	8.7
		GPS	7.1	20.3	11.3	11.0	11.0	11.9	20.0	7.4
	5	GAL	7.0	20.7	11.4	10.8	11.4	11.4	20.4	6.9
		GPS	5.6	21.3	11.6	11.1	11.0	12.4	21.4	5.6
	15	GAL	4.6	22.4	11.7	10.7	11.6	11.8	22.2	5.0
		GPS	3.4	22.7	12.1	11.2	10.8	12.7	23.6	3.5
50–60	0	GAL	10.0	17.4	12.0	10.4	11.1	12.1	17.1	9.9
		GPS	8.9	17.6	12.3	11.1	11.1	12.4	17.3	9.3
	5	GAL	8.6	18.2	12.3	10.5	11.4	12.6	17.8	8.6
		GPS	7.1	18.5	13.0	11.4	11.4	13.0	18.3	7.3
	15	GAL	4.0	20.7	13.6	11.4	12.2	14.1	20.3	3.7
		GPS	2.7	20.3	14.6	12.2	12.3	14.3	20.9	2.7

codes as the 37 PRN codes reserved by the GPS system.

The EGNOS system will provide three services:

– open service (free access but without guarantee),
– commercial data distribution (with guaranteed service),
– safety of life (almost real time integrity), and this service will be the most interesting for all users of European inland waterways, certainly.

The EGNOS user segment is composed of a GPS and/or GLONASS receiver and EGNOS receiver. The two receivers are usually embedded in the same user terminal. As the receiver can process the message in a 6-second duty cycle the integrity time to alarm is limited to the duty cycle time.

EGNOS will be fully operational in April 2009; it is designed for a wide number of applications, including transport on inland waterways. For the users of European inland waterways the problem of the visibility appears in the EGNOS system owning to the three geostationary satellites (GEO) – two operational: Inmarsat–3–F2 Atlantic Ocean Region–East (AOR–E) and Inmarsat–3–F5 Indian Ocean Region–West (IOR–W) located at longitudes 015.5°W and 025°E, respectively and one with status industry test transmissions – Artemis at 021.5°E. The 3 current EGNOS C/A codes are 120, 126 and 124 respectively [Kaplan, E.D.,Hegarty, C.J. 2006].

Due to the environment along the shoreline of the rivers/canals, the risk of losing line-of-sight to GEO satellites is quite high. Obstacles could be mountainous terrain, high buildings, big bridges, or other technical structures (e.g. harbour area, locks).

4 TERRESTRIAL RADIONAVIGATION SYSTEMS

Terrestrial radionavigation system Loran C (Long Range Navigation) is a low frequency electronic position fixing system using pulsed transmissions at 100 kHz. Groundwave ranges of from 800 to 1200 n miles are typical, depending upon transmitter power, receiver sensitivity, and attenuation over the signal path.

On European inland waterways two Loran C chains (6731 and 7499) can be used with three lines of positions: 6731–X, 6731–Z and 7499–X in France and northwest Germany, in particular. As the location of all European Loran C System (Ex–NELS) transmitters are designed for the sea user (Norway Sea and North Sea) first of all, this system cannot be taken into account in the navigation on great European rivers such as the Rhine and Danube.

Eurofix is an integrated radionavigation and communication system, which combines Loran C and DGPS by sending differential satellite corrections to users as time, modulated signal information. At present four Ex–NELS, Boe and Vaerlandet (Norway), Sylt (Germany), Lessay (France), stations transmit Eurofix corrections only, additionally the number of user's receivers is very small. That's why this system cannot be used on inland waterways.

5 AUTOMATIC IDENTIFICATION SYSTEM

Automatic Identification System (AIS) is a ship borne radio data system continuously broadcasting ship identification number (ID), its position, course and speed, and other data to all nearby ships and to shore side infrastructure on a common VHF radio channel. On inland waterways, the data transmission is based on the "Vessel Tracking and Tracing Standard for Inland Navigation" published by the Central Commission for the Navigation on the Rhine (CCNR) and by the European Commission in 2007. This standard describes the so called "Inland AIS" which guarantees 100% compatibility with the maritime AIS system while extending AIS to the needs of inland waterway transportation [Amlacher C. et al. 2007].

Table 3. The integrated systems and their parameters.

Systems	GPS Integrity	Galileo Integrity	Improved RAIM	Redundant System	Redundant Augmentation	System Failure Tolerance	Robustness to Interference
GPS, EGNOS SIS	✓						
GPS, EGNOS SIS, EGNOS through AIS	✓				✓		
GPS, Galileo		✓	✓	✓		✓	✓
GPS, Galileo, EGNOS SIS	✓	✓	✓	✓		✓	✓
GPS, Galileo, EGNOS SIS, EGNOS through AIS	✓	✓	✓	✓	✓	✓	✓

Inland ships, which are equipped with AIS, can utilize the information transmitted from other ships by AIS to improve the traffic image surrounding a traffic situation.

We can distinguish two different applications of AIS in inland navigation:

- for navigation support on board,
- for traffic information and traffic management services.

The AIS transponder as a key element for RIS needs to be installed onboard ships, as well as in base stations on shore. A transponder unit generally comprises three main functional elements, of which one is a Global Navigation Satellite System (GNSS) module with the capability of applying differential GPS or EGNOS corrections to the measurements [Trögl J. et al. 2004].

Based on the data of AIS exchange, the visualization of traffic information on an ENC, so called Tactical Traffic Image (TTI) is enabled. This TTI supports the skipper in his nautical maneuvers.

6 INTEGRATED SYSTEMS

Accuracy of the ship's position is a functional requirement for inland waterways operations. However without integrity information the data received from GPS system and/or DGPS system can only be used with restrictions. Integrity is the ability to provide users with warnings within a specified time when the system should not be used for navigation. Although this may be acceptable for some users, it is not acceptable for other users.

The provision of integrity information by the GPS constellation is however not foreseen in the near future, because only the next generation's satellites block III is expected to provide, among other things, a system integrity solution. Satellites of the nearest block IIF will be without integrity. Therefore, the need of integrity is evident. Nowadays this kind of information can be obtained from EGNOS, and in the future from Galileo. That's why information about the position and integrity can be assured by the integrated systems with these two systems mentioned above.

A discussion of the usefulness of Galileo system for the inland waterways two planned services, Open (OS) and Safety of Life (Sol), will be very interesting for the users. Galileo will provide increased performance through the use of dual (L1 + E5a) or triple (L1 + E5a + E5b) frequency observations as well as improvements in safety through the provision of an integrity message.

The five possible integrated systems and their most important parameters are presented in the Table 3. Let us discuss each parameter:

- GPS integrity. As this integrity is assured by the system EGNOS, it takes place for all integrated systems, except the combination GPS/Galileo,
- Galileo integrity. It is assured by all integrated systems in which one of the systems is Galileo,
- improved RAIM (Receiver Autonomous Integrity Monitoring); as above,
- redundant system; as above,
- redundant augmentation. It is assured by these systems, in which the EGNOS corrections reach the user's receiver through AIS,
- system failure tolerance. It is assured by all integrated systems in which one of the systems is Galileo,
- robustness to interference; as above.

AIS DGPS provision is fully operational in Austria, Slovakia has a pilot system in operation and Bulgaria, Croatia, France, Hungary, Romania, Serbia and Ukraine are currently preparing implementation of similar systems [Amlacher C., Trögl J. 2008].

Several projects utilizing NSS, SBAS and AIS in RIS are already realized in Europe with several more prepared as follows.

6.1 *GALEWAT project*

The GALEWAT (Galileo and EGNOS for Waterway Transport) project, founded by the European Space Agency (ESA) Advanced Research Telecommunications program ARTE–5, aims the realization of a first step towards the introduction of EGNOS and finally Galileo into the upcoming River Information Services (RIS) all across Europe.

Among others, the following topics are subject to the GALEWAT project [Abwerzger C. et al. 2005]:

- identification of user requirements related to AIS and EGNOS service parameters for transport efficiency, waterway transport in particular,

- replacement of conventional RIS local differential GPS stations by direct reception of the EGNOS signal in shipboard transponders,
- bridging outages of the EGNOS SIS by retransmitting the EGNOS differential corrections and integrity data via AIS base stations in areas without direct EGNOS reception,
- analysis and validation of EGNOS, integrated into the AIS transponder concept, being capable to meet the user and service requirements.

The GALEWAT is composed of five segments:

- ship, several ships, all equipped with standard equipment (AIS transponders with GPS and DGPS receivers), one additionally with extended equipment which allows the position fixes in different modes (GPS stand alone, GPS + IALA DGPS, GPS + EGNOS SIS, GPS + EGNOS AIS),
- shore, mainly comprises two AIS base stations which must receive the EGNOS signal (with the differential corrections) from GEO satellites and then broadcast re–formatted EGNOS information via the AIS data link,
- regional, terminals located nearby strategic points, which are connected to several shore elements to gather tactical traffic information of the area,
- operator, e.g. national control center storing all traffic information provided by RIS in a large database,
- external, which consists fundamentally of web interface where external users can retrieve relevant traffic information of the area.

The public demonstrations of this system in Vienna (Austria), Lisbon (Portugal) and Constanta (Romania) have already been successfully executed.

6.2 *MARGAL project*

The MARGAL project, prepared by Kongsberg Seatex (Norway) and eight European concerns, is based on AIS technology to monitor vessels and to deliver EGNOS differential corrections and integrity warning to applications where direct reception signal is not possible [Kristiansen K. et al. 2005].

This project is a harmonized and seamless solution for maritime navigation for European ports and inland waterways. The project MARGAL has shown that changes to the actual version (2.3) of RTCM message format and to the AIS handling of message 17 (RTCM message) are needed to meet, respectively, the accuracy requirements for new services and the time to alarm requirements. The current EGNOS and the future Galileo integrity services can be utilized in operational applications like remote pilotage and queue systems for ports and locks [www.margal.net].

6.3 *MUTIS project*

MUTIS (Multimodal Traffic Information Services) is a project within the ARTES (Advanced Research in Telecommunications Systems) 3 program of ESA. This project is aiming at the study of the feasibility of the introduction of satellite based communication LEO (Low Earth Orbit) into the upcoming RIS across Europe [Trögl J. et al. 2004].

The demonstration within MUTIS will focus in the Danube waterway from Vienna in Austria to Constantia in Romania on the length of approximately 1700 km. A vessel is equipped with necessary facilities as EGNOS receiver, PC and LEO & GSM communication. In this way the vessel transmits every 15 minutes own position obtained from GPS system and EGNOS system over a LEO service provider to database & control station. Position information and data from/to the vessel will be transmitted to/from this station via several channels:

- GSM as a terrestrial wireless system,
- GLOBALSTAR as “big LEO” satellites system,
- IRIDIUM as alone satellite system,
- THURAYA as a low-cost GEO satellite system.

6.4 *MARUSE project*

The MARUSE project, part of the EU 6th framework programme, was realized in the years 2005–2007. The main objective of this project is to demonstrate Galileo differentiators and the benefits of using Galileo and EGNOS in maritime and inland waterways applications. The technology development consists of two major elements: a user terminal and a local infrastructure [www.maruse.org].

One of four demonstrations took place at the Danube Iron Gate I (two locks) in Serbia in June 2007. GPS differential corrections are transmitted via the AIS data link (AIS Msg.17). The vessel is equipped with a Maritime User Terminal utilizing a standard AIS transponder augmented by a GPS/GLONASS positioning element and a digital compass for a determination of vessel heading. The AIS transponder system is linked to an ECDIS viewer providing the skipper with the TTI and the integrity information. In the future the vessel’s position will be fixed by a third NSS – Galileo [Christiansen S.E. et al. 2007].

7 CONCLUSIONS

- the measurements realized within the framework of several European projects showed the full usefulness of SNS, SBAS and AIS on inland waterways, particularity the great European rivers Rhine and Danube,
- as the distribution of satellite azimuths of each SNS depends on observer’s latitude, the position accuracy of the ship sailing with high river coast on both sides depends on its geographic location also,
- the results obtained from measurements using EGNOS signals (GALEWAT project) showed that GPS augmented by EGNOS from SIS can be a good candidate for inland waterway safety–critical applications with required accuracy below 10 m, high system availability, and protection level below 25 m,

– the use of AIS to broadcast EGNOS data (GALEWAT project) is not introducing any significant degradation of performance compared to the EGNOS performance directly obtained with the SIS (DoRIS project),
– IALA DGPS reference stations situated today at seashore first of all can be installed and used inland, e.g. four stations already installed in Germany,
– the actual projects, e.g. MARGAL, MARUSE, include the implementation of software defined vessel's receivers making a smooth transition from EGNOS to Galileo possible,
– integrity of the systems built around and the needs of inland navigation can be assured by these integrated systems only, one of which is the present EGNOS system, and in the future Galileo system also.

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9.2 Electronic reporting of ships in the RIS system

A. Lisaj
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: This article presents the principles of data transmission and processing in a module of duplex transmission of messages as required by ship reporting in the RIS (River Information Services) system. Technical specification of messages intended for ship commanders is analyzed. Data standards in harmonized River Information Services on inland waterways are presented. Furthermore, the analysis covers message structures, encrypting in XML format for electronic reporting by ships. Finally, the author evaluates the advantages of introducing the RIS system for the safety of inland vessel traffic and the effect of the system on environmental protection.

1 INTRODUCTION

RIS (***River Information Services***) is a system that aims at the implementation of river traffic information services co-ordinating planning and logistics of transport.

RIS consists of advanced functions and services bringing operational advantages (e.g. immediate navigational decisions) and strategic ones (e.g. resources planning) for its potential users – inland shipping administrations – captains, terminal managers or lock operators.

Modern radio-communications and information technologies are used in inland transport. Ships are equipped with portable computers which have access to the Internet via a mobile telephone network. Besides, satellite positioning systems, electronic charts and inland AIS transponders are being developed and implemented.

Shore installations include radar stations with target tracking functions and ship reporting systems with interconnected databases.

Several technological innovations connected with RIS have been introduced in the sector of inland navigation [1]:

- electronic navigational charts (ENC) for displaying information on fairway situation and ship positions,
- Internet applications and inland ECDIS for messages for captains,
- electronic reporting systems for collecting data on voyage-related information (ship and cargo),
- vessel tracking and locating, such as automatic identification systems (AIS) for automatic reporting of ship's position.

2 BASIC FUNCTIONS AND OBJECTIVES OF ELECTRONIC SHIP REPORTING IN RIS

Functions and objectives of electronic ship reporting in inland navigation have been developed in line with the principles which aim to [4]:

- facilitate electronic data interchange between relevant authorities of the EU member states and inland navigation operators,
- use standardized notifications in communications between a ship and management centre in order to ensure compliance with mandatory rules in the adopted standards,
- use recognized international lists of codes and classifications,
- use unique European ship identification numbers.

The tasks of electronic ship reporting in the RIS system are as follows [3]:

1. Facilitation of data structure transfer in conformity with adopted EDI (Electronic Data Interchange) standards.
2. Exchange of information between inland navigation partners.
3. Sending dynamic information on a voyage at the same time to many participants.
4. Consistent use of the **UN/EDIFAC standard** (Electronic Data Interchange for Administration, Commerce and Transport) within the EU, according to its directive on data transmission procedures **UNTDID** United Nations Trade Data Interchange Directory).
5. Inland traffic management.

Table 1. RIS function and procedures of the messages

RIS Service and Function	Ship-to-authority	Messages in the procedures Authority-to-ship	Authority-to-authority
Traffic management	**ERINOT (VES)** **ERINOT (CAR)**	**ERIRSP** Notices to skippers	**ERINOT (PAS)**
Calamity abatement	**ERINOT (VES)** **ERINOT (CAR)** PAXLST	**ERIRSP** Notices to skippers	**ERINOT (PAS)** PAXLST
Transport management	**ERINOT (VES)** **ERINOT (CAR)** CUSCAR, CUSDEC	**ERIRSP** Notices to skippers	**ERINOT (PAS)** CUSCAR, CUSDEC
Statistics	**ERINOT (VES)** **ERINOT (CAR)** PAXLST CUSCAR, CUSDEC		
Waterway charges	**ERINOT (VES)** **ERINOT (CAR)**	**ERIRSP**	
Border control	PAXLST	**ERIRSP**	PAXLST
Customs services	CUSCAR, CUSDEC	**ERIRSP**	CUSCAR, CUSDEC

6 Transfer of complete information on locks and bridges and calamity situation.
7 Loading / unloading management and container terminal operation monitoring.
8 Border crossing control.
9 Services to passengers of inland ships.

3 PRINCIPLES OF DATA TRANSMISSION AND PROCESSING IN THE RIS SYSTEM

Technical specifications defining the principles for data transmission of ship reporting in the RIS comply with the relevant EU directive [2].

The directive precisely covers such issues as:

– introduction of Standard Message Types (SMT));
– criteria and principles for data transmission – UN/EDIFACT;
– specifications of the message type directory EDMD (Edition 98.B, recommended by IMO);
– specification of the code list (CL);
– introduction of data standardization elements (Trade Data Elements Directory (TDED)).

3.1 *Data transmission standards in the RIS system*

In conformity with the EDIFACT standard, data processing in the RIS system makes use of XML format (Extended Mark-up Language) [6] in which:

– EDIFACT and XML utilize the same data structure and code list.
– presently these versions are being tested: ebXML, eDocs and BICS 2.0.

3.2 *Classifications and code lists in the EDIFACT messages*

The following classifications shall be used in inland electronic ship reporting [3,6]:

1 Vessel and convoy type
2 Official ship number (OFS)
3 IMO ship identification number (IMO)
4 ERI (Electronic Reporting International) ship identification number
5 UN Dangerous Goods number (UNDG)
6 International Maritime Dangerous Goods Code (IMDG)
7 United Nations codes for the representation of the names of countries
8 United Nations code for trade and transport locations (UN/LOCODE)
9 Fairway section code
10 Terminal code
11 Freight container size and type code (ISO)
12 Container identification code (ISO)
13 Package type code
14 Nature of cargo

The following table (tabl. 1) defines the usage of the messages:

The following messages shall be used in electronic ship reporting on inland waterways [6]:

1 **ERINOT**, means "ERI Notification Message", message with the following types:
   – Transport notification from vessel to authority (identifier "VES"), from ship to shore
   – Transport notification from carrier to authority ("CAR"), from shore to shore
   – Passage notification ("PAS"), from authority to authority and the following functions to show what can be expected:

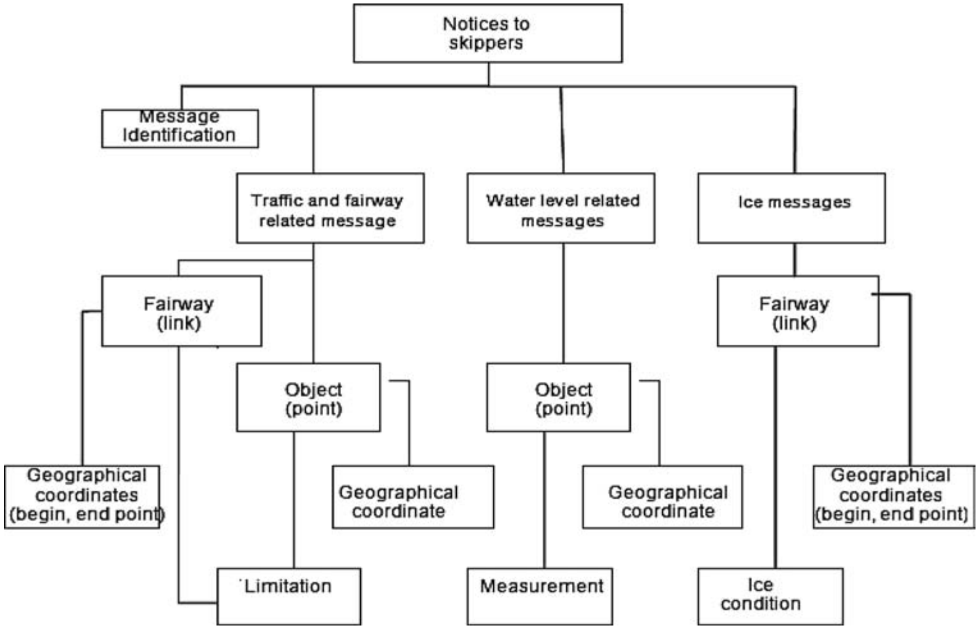

Figure 1. Structure of the Notices to Skippers.

2 **ERIRSP**, means "ERI Response Message",

- **PAXLST**, means the "Passenger List Message", including passengers, crew and service personnel.
- **CUSCAR**, means the "Customs Cargo Report Message",
- **CUSDEC**, means the "Customs Declaration Message".

The reporting procedure shall always start with the **ERINOT** message and send additional data by the PAXLST, CUSCAR and CUSDEC messages.

3.3 *Methods of remote data transmission in electronic ship reporting*

The following communications means have been proposed for use in message transmission within electronic ship reporting [5]:

1 VFH radio station.
2 ATIS (Automatic Transmitter Identification System) identifying ship's calling, e.g. while approaching a lock, in a computer-based system of traffic management.
3 inland AIS transponder (Automatic Identification System).

4 DATA STANDARDS IN MESSAGES FOR SHIP SKIPPERS

Navigation messages, with navigation information for inland skippers (fig.1) about a geographical object, have the following information sections [4]:

1 Identification of the message.
2 Fairway and traffic related message.
3 Water level related messages as:

- Water level messages;
- Least sounded depth – messages;
- Vertical clearance – messages;
- Barrage status – messages;
- Discharge messages;
- Regime messages;
- Predicted water level – messages;
- Least sounded predicted depth – messages;
- Predicted discharge – messages.

4 Ice messages.

5 SUMMARY

Electronic ship reporting in the transmission of message for ship skippers and inland navigation management centre enables the RIS system achieve three basic goals:

1 to enhance the safety of transport – minimize the number of:

- injured persons,
- fatal casualties,
- untypical situations in a voyage;

2 to make transport efficient:

- maximize the capacity of waterways,
- maximize the use of ship cargo capacity,
- minimize voyage time,
- reduce work effort of RIS users,
- reduce transport costs,
- reduce fuel consumption,

– ensure efficient and cost-effective connections for intermodal transport,
– make efficiently operating harbours and terminals accessible;

3 to make transport environment-friendly:

– reduce threats to the environment,
– reduce pollution.

The development of standardized RIS interfaces will make it possible to generate wide-range transparent information processes and smooth data exchange between all participants of inland navigation.

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9.3 The criterion of safety navigation assessment in sea-river shipping

W. Galor
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: Sea–river ships can connect the area inside of land with oversea places without of indirect transshipment. In many cases the sea-river ships move on waterways (natural and artificial) inside of land for hundreds kilometres. Navigation in inland waters has to meet the same requirements as those for pilot navigation. This is due to the relations between the ship size and other objects on water area. These ones caused the navigation more hard then on open seas. The paper presents the criterion of safety assessment of navigation during sea-river ships manoeuvring ship in inland waters.

1 INTRODUCTION

Process of ships movement in water area should be safely. Its estimation is executed by means of notions of safety navigation. It may be qualified (Galor W. 2001) as set of states of technical, organizational, operating and exploitation conditions and set of recommendations, rules and procedures, which when used and during leaderships of ship navigation minimize possibility of events, whose consequence may be loss of life or health, material losses in consequence of damages, or losses of ship, load, port structures or pollution of environment. Very often, the sea-river ships move on waterways (natural and artificial) inside of land for hundreds kilometres. The manoeuvring of ships on each water area is connected with the risk of accident, which is unwanted event in results of this can appear the losses. There is mainly caused by unwitting contact of ships hull with other objects being on this water area. The safety of ship's movement can be identified as admissible risk, which in turn can be determined as:

$$R_{adm} = P\ C_{min} \tag{1}$$

where: R_{adm} = admissible risk, P_A = probability of accident and C_{min} = acceptable losses level.

As a result, a navigational accident may occur as an unwanted event, ending in negative outcome, such as:

- loss of human life or health,
- loss or damage of the ship and cargo,
- environment pollution,
- damage of port's structure;
- loss of potential profits due to the port blockage or its parts,
- coast of salvage operation,
- other losses.

The inland waterways are restricted areas those where ship motion is limited by area and ships traffic parameters. Restricted areas can be said to have the following features:

- restriction of at least one of the three dimensions characterizing the distance from the ship to other objects (depth, width and length of the area),
- restricted ship manoeuvring,
- the ship has no choice of a waterway,
- necessity of complying with safety regulations
- set for local conditions and other regulations.

In a few cases, especially for ports situated inside of land, there are the waterways and canals with great lengths of hundreds kilometres. Thus the navigation on such waterways is different than on approaching waterways and coastal water areas. The realization of navigation on limited water areas is consisted on (Galor W. 2005):

- planning of safety manoeuvre,
- ship's positioning with required accuracy on given area,
- steering of craft to obtain the safety planned of manoeuvre,
- avoiding of collision with other ships.

Approach channels to port and port water area are characterised by occurrence of port structures. These constructions are result of activity of man and embrace aquatic or under-water structure which together with installations, builder's devices connected with them and other advisable necessary equipment to realize of its intended function to state whole of technical using. From sight of view limitation of movement in water area, ports structures envelop following component:

- objects arising in result of executing of dredged works such port and shipyard water, especially and basin, sea and lagoon fairways, approach channels, turning basins,
- channels,

Figure 1. The lock in Czyżykówko on Wisła – Odra waterway.

- wharfs determining of water area coast and largely making possible berthing to them and mooring of ships,
- constructions of coast protection such breakwaters, under-water thresholds, strengthening of bottom, scarp of fairways deepened,
- constructions of fixed navigational marks such lighthouses, situated on shore of sea water area and aquatic, light lines and navigational marks, navigational dolphins,
- locks (fig.1),
- structures situated in area of sea harbour, in particular isles of berthing and trans-shipment, shipping foot-bridges,
- port structures, situated in area of sea harbour in particular breakwaters, breakers of waves, wharfs trans-shipment and berthing and other,
- structures connected with communication, in particular road – bridges, railway, submarine tunnels,
- structures connected with exploitation of sea bottom (drilling towers, platforms, submarine pipelines).

Besides to number to them it is necessary: constructions of floating navigational marks, in particular anchored navigational buoys.

2 THE CRITERION OF SHIPS SAFETY ASSESSMENT

The restricted area is characterized by a great number of factors being present at the some time. It caused that possibility of navigational accident in these areas is more then in other ones. It means the navigation safety is lower in restricted areas. The assessing of navigation safety requires the application of proper criteria, measures and factors. The criteria make it possible to estimate the probability of navigational accident for certain conditions. The ship during process of navigation has to implement the following safety shipping conditions:

- keeping the under keel clearance,
- keeping the proper distance to navigational obstruction,
- keeping the proper air drought,
- avoid of collision with other floating craft,

To determine and analyse the safety, especially in the quantitative manes, the necessary to select values that can by treaded as a safety measures. It permits to determine the safety level by admissible risk (Galor W. 2001a):

$$R_a = P_A\,[\,d(t)_{max} < d_{min}\ (0 < t < T_p)]\ for\ c < C_{mi} \quad (2)$$

where: $d(t)_{max}$ = distance of craft hull to other objects during manoeuvring, d_{min} = least admissible distance of craft hull to other objects, T_p = time of ships manoeuvring, c = losses as result of collision with object and C_{min} = the acceptable level of losses.

Because the losses can be result different events, the following criterion of safety assessment will be used:

1 Safety under keel clearance (SUKC)
2 Safety distance to structure (SDS)
3 Safety distance of approach (SDA)
4 Safety air drought (SAD)

Thus, there are many categories of risk due to ship movement in water area. In each case the accident rate (probability) is determined for each of the accident categories. The overall risk of ship movement in water area in then the sum of these single, independents risks:

$$R_o = R_g + R_n + R_c + R_{ad} \quad (3)$$

where: R_o = .overall risk of ship movement in water area, R_g = risk of grounding, R_n = risk of collision with navigations obstructers, R_c = risk of collision with other ships and R_{ad} = risk of impact the object over the ship.

3 SAFETY UNDER KEEL CLEARANCE (SUKC)

The underkeel clearance is a vertical distance between the deepest underwater point of the ship's hull and the water area bottom or ground. That clearance should be sufficient to allow ship's floatability in most unfavourable hydrological and meteorological conditions. Consequently:

$$H \geq T + R_B \quad (4)$$

where: H – depth, T – ship's draft and R_B – safe underkeel clearance (UKC).

The safe underkeel clearance should enable the ship to manoeuvre within an area so that no damage to the hull occurs that might happen due to the hull impact on the ground. A risk of an accident exists when the under keel clearance is insufficient. When determining the optimized UKC we have to reconcile contradictory interests of maritime administration and port authorities. The former is responsible for the safety of navigation, so it wants UKC to be as large as possible. The latter, wishes to handle ships as large as possible, therefore they prefer to accept ships drawing to the maximum, in other words, with the minimized UKC. The maximum UKC requirement entails restricted use of the capacity of some ships, which is ineffective in terms of costs for ports and ship operators. In the extreme cases, certain ships will resign from the services of a given port. Therefore, the UKC optimization in some ports will be of advantage. It is possible if the right methods are applied. Their analysis leads to a conclusion that the best applicable methods for UKC optimization are the coefficient method and the method of components sum.

In the coefficient method one has to define the value R_{min} as part of the ship's draft:

$$R_{min} = \eta \, T_c \tag{5}$$

where: $\eta =$ coefficient and $T_c =$ deepest draft of the hull. The applied coefficient η values range from 0.04 to 0.4 (Mazurkiewicz B. 2008). The other method consists in the determination of R_{min} as the algebraic sum of component reserves [6] which accounts for errors of each component determination:

$$R_{min} = \sum R_i + \delta_r \tag{6}$$

where: $R_i =$ depth component reserves and $\delta_r =$ sum of errors of components determination.

The UKC is assumed to have the static and dynamic component. This is due to the dynamic changes of particular reserves. The static component encompasses corrections that change little in time. This refers to a ship lying in calm waters, not proceeding. The dynamic component includes the reserve for ship's squatting in motion and the wave impact. One should emphasize that with this division the dynamic component should also account for the reserve for ship's heel while altering course (turning).

4 SAFETY DISTANCE TO STRUCTURE (SDS)

The accessible port water area (for given depth) warrants safety manoeuvring for fulfill condition:

$$\omega \in \Omega \tag{7}$$

where: $\omega =$ requisite area of ship's manoeuvring and $\Omega =$ accessible water area.

Ships contact with structure can be intentional or not. Intentional contact steps out when ship berthing to wharf. During this contact energy dependent from virtual ship masses and its perpendicular component speed to the wharf is emitted. In result of ship pressure on wharf comes into being reaction force. Both emitted energy during berthing and bulk reaction force cannot exceed admissible value, definite by reliability of ship and wharfs. These values can be decreased by means of fenders, being usually of wharf equipment. Ship should manoeuvre in such kind to not exceed of admissible energy of fender-structure system. Unintentional contact can cause navigational accident. Process of ship movement in limited water area relies by suitable manoeuvring. During of ship manoeuvring it can happen the navigational accident. Same events can occur strike in structures, when depth of water area is greater than draught ship. There are usually structures like wharf, breakwater, etc., and also floated objects moored to structure.

5 SAFETY DISTANCE OF APPROACH (SDA)

Where:

The fundamental measure of ships passing is distance to closest point of approach (DCPA). Its value should be safety, it means:

$$DCPA \,.\!\geq\!.\, DCPA_{min} \tag{8}$$

where: $DCPA =$ distance to closest point of approach and $DCPA_{min} =$ acceptable distance to closest point of approach.

The accident can happen; when above condition will not be performance. Knowing the number of entries of ships in a year (annual intensity of traffic), one can determine the probability of ships collision for one ship transit:

$$p_A = \lambda / I_R \cdot t \tag{9}$$

where: $p_A =$ probability of ships collision in one transit, $\lambda =$ accident frequency, $I_R =$ annual traffic intensity and $t =$ given period.

Determinate the probability of accident for given number of ship transits it can used the following formula (Galor W. 2004):

$$P_{A(N)} = N \cdot p_A = I \cdot T \cdot p_A \tag{10}$$

where: $P_{A(N)} =$ probability of accident for given ship transit number and $N =$ number ship of transits.

This relationship is linear because implies proportional growth of probability to considered of ship number transit. More adequate manner is use the statistical models described the accident probability. Because accidents are infrequent events thus it can be used recurrent models. One of them is geometrical distribution:

$$P_{A(N)} = 1 - (1 - p_A)^N \tag{11}$$

Figure 2 presents the probability of navigation accident for linear and geometrical distributions in function of ships transit numbers.

It results that for given value of accident probability (for example 0.95) for linear distribution it is achieved up to about three times less than for geometrical distribution.

6 SAFETY AIR DROUGHT (SAD)

Air drought is distance over ship, when manoeuvre under construction. They mainly consist:

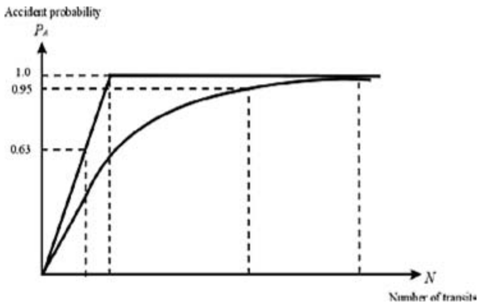

Figure 2. Probability of accident in function of transits number for linear and geometrical distributions.

Figure 3. The road bridge over Noteć river in Santok (Poland)-(Nadolny G. 2005).

- bridges (road, railway) over waterway (fig. 3),
- high voltage lines,
- pipelines over waterway,

The condition of safety ship movement is following:

$$H_S < H_C \tag{12}$$

where: $H_S =$ the height of highest point of ship and $H_C =$ the height of lowest point of construction over waterway.

In many cases, the sea-river ship's superstructure is regulated. It permits to decrease of ships height. Also other elements of ship's construction can be disassembled – for instance masts of radar antenna, radio etc.

7 CONCLUSION

The sea-river ships move on waterways (natural and artificial) inside of land in many cases for hundreds kilometres. The ship can pass natural objects (coast, water bottom) and artificial objects (water port structures-locks, bridges etc.). Also many other ships can manoeuvre on area. It caused that the navigation in inland waters is harder than on open seas. The criterions of safety assessment of ship movement need more precisely of qualify. The risk can be used as measure of safety. This risk is a sum of independent components connected with different possibilities of potential accidents. They are a result of unwanted contact with objects on inland water area. The presented above consideration can permit to analysis of safety sea-river ships in inland shipping.

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9.4 Target tracking in RIS

A. Stateczny & W. Kazimierski
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: The article treats of problems bound with the tracking of surface water targets in RIS systems. A concept of RIS has been briefly presented, indicating the need for locating in them the tracking and tracing of ships. The most popular sensors used for the purpose have been characterised, the most important relevant documents have been presented and the requirements set for tracking systems have been described.

1 INTRODUCTION

The River Information System (RIS) is a package of solutions for the needs of inland shipping, which has been worked upon for a dozen years by representatives of most European countries. The underlying foundation of this concept is harmonising the activities of all kinds of enterprises, institutions and other users of inland waterway networks in Europe. It is high time Poland too should join the group of countries involved in this undertaking. Directive 2005/44/WE of the European Parliament and Council of Europe, along with respective regulations of the Commission of European Communities (414/2007 and 415/2007) oblige the member countries to introduce this type of system. At the same time they specify requirements pertaining to its implementation, pointing out among other things, which services should be covered by it. Among them are Traffic Information service and Traffic Management. According to assumptions, both should be based on tracking and tracing of vessels conducting navigation in inland waters.

Within the framework of European projects there was called a Tracking and Tracing Expert Working Group, whose work effected in guidelines providing the basis for designing tracking systems in RIS (Tracking and Tracing Expert Group, 2005). They were subsequently accepted by practically all organisations regulating RIS services in Europe.

The present article sets forth the subject matter related to target tracking in RIS and the demands made on it.

2 VESSEL TRACKING AND TRACING

Defining vessel tracking in RIS requires the taking into consideration of a kind of semantic dualism, ushered in by the European Law in force and its translation into English, as the European documents use the English words *tracking* and *tracing*, which in both cases may be translated into Polish as *sledzenie*. Therefore, in official translations two separate concepts were introduced. And so, according to Regulation of Commission of European Communities Nr 414/ 2007 13 March 2007 the following definitions were introduced:

– *Vessel tracking* (Polish *sledzenie*) means the function of maintaining status information of the vessel, such as the current position and characteristics, and – if needed – combined with information on cargo and consignments.
– *Vessel tracing* (Polish *namierzanie*) means the retrieving of information concerning the whereabouts of the vessel and – if needed – information on cargo, consignments and equipment.

Both definitions partly overlap each other, and their differentiation becomes more complete, when the various applications are known for information obtained in effect of tracking and tracing vessels. The issue here is first of all division into static information, pertaining to characteristics of the vessel or the voyage, and into dynamic information, pertaining to the vessel's current navigational situation. Nevertheless, in almost all RIS-related studies, both concepts are linked to each other, being two parts of a conceptual whole.

3 TARGET TRACKING REGULATING DOCUMENTS IN RIS

The problem of tracking targets in inland waters appeared automatically at the moment of introducing supervision of barges and other river vessels. The traditional technique applied for this purpose was radar tracking backed up by various communication technologies, starting from VHF up to cellular telephony. The next step forward is including tracking in the RIS system.

Since the emergence of the concept of harmonised services for inland shipping in the scope of RIS a number of documents have been prepared, which are mainly the result of international programmes under the aegis of European Communities. The main participants of those programmes were countries and firms bound with shipping in west Europe's largest rivers. At the same time, the preparation of RIS standards was the activity of Central Commission for Navigation on the Rhine (CCNR), and Permanent International Association of Navigation Congresses (PIANC). The subject matter of target tracking has always been an essential part of RIS services.

In 2000 the programme Inland Navigation Demonstrator for River Information Services (INDRIS) was completed, organised within the framework of 4. PR of the Directorate-General for Transport and Energy of the European Commission, which is the first pan-European attempt at implementing the idea of harmonised RIS services. Within its scope there were conducted a few demonstrations of RIS concept on the main inland routes of West Europe. The possibility was indicated of making use of techniques applied in marine VTS centres (Vessel Traffic System), also for tracking inland traffic. It was to be based on data obtained from shore radar, but AIS was taken account of as a source of additional information about targets. (INDRIS, 2000)

Within the scope of 5PR two large RIS-related programmes were started. The first of them was ALSO DANUBE, which lasted from 2002 to 2003, and the other was COMPRIS, a sort of continuation of INDRIS, which lasted from 2000 to 2005. The first was oriented to implementing new technologies of improving shipping on the Danube, the other developed the concept of pan-European RIS within an international consortium (more than 11 member states). In both projects the significance of AIS was stressed both for tracking and tracing targets. At the same time, in COMPRIS programme the attention was directed to the inaccuracies of radar tracking, resulting both from its characteristic and from the specificity of traffic in inland water areas, with frequent manoeuvres, especially by course (COMPRIS, 2004). The importance of data fusion and information was also stressed, acknowledging that radar will be only one of the sensors within the tracking system (COMPRIS, 2005).

Apart from programmes described, within the scope of RIS European platform and with the support of Central Commission for Navigation on the Rhine as also the Danube Commission, expert groups were called with the objective of working out standards and requirements related to RIS. One of the groups handled problems of target tracking and tracing. Its work was based on guidelines for RIS systems worked out by PIANC and approved by CCNR in 2004 (CCNR, 2004). It was pointed out in the study that AIS-based tracking systems supplement radar tracking, which remains the basic source of information about vessel tracking. The experts, without negating this fact, concentrated almost exclusively on AIS development in two variants – Inland AIS and AIS-IP. Their activity effected in standards, worked out in 2005, concerning tracking and tracing of vessels in inland shipping (Tracking and Tracing Expert Group, 2005), which were further adopted by CCNR (CCNR, 2006), and also included in a resolution by European Economic Commission at the UN (UNECE, 2007). They state that a complex tracking system should be made up of various types of sensors. The AIS system, however, is indicated as the unquestionable leader. It may in a way seem amusing that in the document it is said in one place that radar should be the basis for the tracking system, followed by over 100 pages of considerations pertaining to the AIS system. In this way, a clear pro-AIS trend looms out among RIS designers, on a scale surprisingly large in places. For example the DoRIS system, which regulates navigation in the Austrian part of the Danube is based exclusively on AIS and does not avail itself of a radar station. The question arises here about the safety and reliability of Inland AIS.

In the writer's opinion, two things determine the popularity of AIS. In the first place, the high accuracy of dynamic information obtained concerning the vessel's movement (assuming the correct functioning of the system and the ship's sensors; in the second place, the possibility of widening these data by static information about the vessel's dimensions, cargo, port of destination etc. In neither respect does radar stand comparison with AIS.

From 2003 parallel work went on on introducing the DoRIS system of river services, covering the Austrian part of the Danube. In this system, too, AIS was indicated as the main source of information concerning vessel tracking and tracing.

As can be observed, in only a few years there emerged a lot of institutions and consortiums in connection with RIS introduction in Europe, which brought fruit in many documents related to RIS standards and requirements as a whole and vessel tracking in particular. For the time being, the key documents in this area are the RIS Directive, accepted by the European Parliament and Council in 2005 (EP and UE Council, 2005), two Regulations 414 and 415 of 2007 by the Commission of the European Communities, 2007 a & b, as also the previously mentioned Resolution No.63 of the European Economic Commission at the UN (UNECE, 2007). The RIS Directive is at the moment the basic legal act in Europe related to RIS. It establishes the framework for distribution and using harmonised river information services (RIS) in the Community. At the same time, in matters concerning technical details the Directive refers to the works of European Commission, which issued two regulations on the subject of tracking in RIS. Regulation 414/2007 contains technical guidelines concerning planning, implementing and operational use of river information services (RIS), whereas Regulation 415/2007 pertains to technical specifications related to systems of vessel traffic control within the scope of RIS.

4 PLACE OF TRACKING IN THE RIS CONCEPT SYSTEM

According to the EU Directive, but also to some earlier works, river information services are a few kinds of services related to inland shipping, whose harmonisation and standardisation are to serve

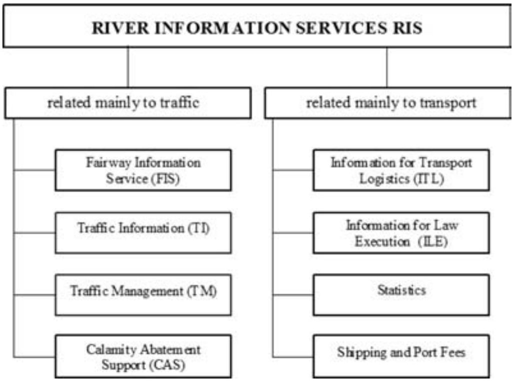

Figure 1. River information services in RIS.

objectives resulting from general European needs in the scope of surface transport. Three basic objectives of introducing RIS were defined in Regulation KE 414/2007 describing goals to be attained:

– transport should be safe;
– transport should be efficient;
– transport should be friendly to the environment.

The realisation of the above general goals, and also partial objectives resulting from them, should be possible by supporting particular tasks bound with inland fleet management. They can be divided into three groups with respect to "arenas" in which they are realised (EC, 2007a):

– arena of transport logistics, in which parties initiating transport cooperate with parties organising transport (e.g. senders, consignees, loaders, forwarders, freight brokers, shipowners);
– arena of transport, where the parties organising the transport cooperate with parties realising transport (e.g. shipowner, terminal operators);
– arena of traffic, in which parties realising transport (e.g. vessel masters and navigators) cooperate with parties managing the resulting vessel traffic (e.g. respective authorities managing the traffic).

Looking for a place for vessel tracking in this flowchart, it will certainly be found among tasks realised in the last arena. In order to present the location even more accurately, in Fig.1 there have been presented particular RIS services, dividing them according to Regulation 414/2007 into services related mainly to traffic and to services related mainly to transport. It should be noticed that a few services may be used for performing RIS tasks.

In Fig. 1 the services where target tracking can be used have been marked in blue. Regulation 414/2007 divides particular RIS services into RIS subservices, which are in turn realised by means of respective RIS functions. Table 1 presents a division of tracking-related services. Specifying the remaining services is not necessary in the aspect of the study's subject matter. It should be noted, however, that information on vessel traffic can be used in services other than those marked, although they are not directly bound with them. For example, for calamity abatement support information on vessel traffic seems to be essential.

In the RIS philosophy three information levels have been introduced (EC, 2007a):

– information on fairways (FI);
– tactical traffic information (TTI);
– strategic traffic information (STI).

From the tracking point of view it is particularly essential to distinguish between the last two. Traffic-related services cover mainly these two information levels.

Tactical traffic information is information affecting the vessel master's or VTS operator's immediate decisions made in relation to navigation in real navigational traffic and concerning local traffic. Strategic traffic information (STI) signifies information affecting medium- and long-term decisions made by RIS users (EC, 2007a).

As sources of the tactical image, the radar, electronic chart and AIS are mentioned. This information can be gathered directly on the ship or provided by the VTS centre. The strategic traffic image is worked out at the RIS centre and is delivered to the users on request. Strategic traffic area includes all vessels of essential significance present in the RIS area with their characteristics, determination of cargo and position, presented as a table or plotted on an electronic chart. So it seems that in a certain generalisation the tactical traffic image corresponds to the concept of tracking, and the strategic traffic image is based on the concept of tracing. It should be remembered, however, that both tracking and tracing provide different kinds of information, and joining them gives the fullest tactical and strategic traffic image.

It is surprising that in the functional decomposition of RIS services contained in regulations of the Commission for European Communities, in the part related to traffic, there is no function realising the presentation of vessel movement parameters, which are of key significance both for solving current collision situations and determining, say, the time of vessels passing each other, or time of reaching the lock. In the writer's opinion, lack of such information seems to be a gross oversight on the part of the authors of the task-service RIS concept, as it is difficult to imagine constructing TTI or STI without such information. Only in the service Traffic Management there appear functions VTS.2 and VTS.3, in which use is made of information pertaining to vessel traffic.

The essence of vessel traffic control within the scope of RIS was presented in more detail in Regulation 415/2007 (EC, 2007b). It was acknowledged in it that one task of the VTS system was to support active navigation of vessels in the area. Three stages of navigation were introduced there:

– navigation, prediction in medium time;
– navigation, prediction in short time;
– navigation, prediction in very short time.

Prediction in medium time denotes observation and analysis of water traffic in advance of a few minutes to an hour. The Master considers in that time possibilities of approaching, passing and overtaking other vessels. The required image exceeds the range of deck radar, hence VTS information support may prove necessary. This is certainly one of the main areas of making use of tracking.

Prediction in short time is the decision-making stage in the navigational process. Information concerning traffic affects the navigational process, including undertaking actions aimed at avoiding possible collision. In this stage, other vessels are observed present at a short distance. In particular, it is essential to track using the ship's sensors, but shore centre support may prove equally essential.

Prediction in very short time is the operational stage of the navigational process that consists in realising decisions made earlier and monitoring the results of such activities. Information required in this case from other vessels are bound with the conditions of a given vessels, such as relative position and relative speed. In this stage it is necessary to give very accurate data obtained by means of tracking.

As far as making use of tracking goes, the service *Traffic Organisation* is equally essential. It concerns traffic operational control and the planning of the vessel's movement in order to avoid traffic jams and dangerous situations. This service is particularly important with high traffic intensity or in situations, where special transports may affect normal traffic in waterways.

To sum up it can be stated that tracking vessels finds application within RIS for building a mainly tactical, but also strategic traffic image. This in turn is used by vessel control service and directly by navigators on inland shipping vessels.

5 REQUIREMENTS SET FOR TRACKING IN RIS

The basic documents presenting the standards and requirements pertaining to tracking in RIS are the previously mentioned Resolution of European Commission 414/2007 (EC, 2007a), and also resolution 63 of the European Economic Commission at the UN (UNECE, 2007), being the approval of CCNR Standards, which in turn are the result of work of an expert group called by the European RIS platform (CCNR, 2006; Tracking and Tracing Expert Group, 2005). It should be noticed, however, that in all these documents references can be found to IALA work related to requirements in VTS vessel management systems.

Standards for tracking devices in inland waters can be considered in two ways. Firstly, from the ship's side, that is as requirements for devices mounted on the vessel, and secondly from the VTS side, as requirements for shore devices.

In the first case two documents seem to be crucial. The first of them contains requirements prepared by CCNR concerning radar devices mounted on vessels navigating on the Rhine (CCNR, 2004). These requirements in turn became the basis for working out guidelines by the European Telecommunication Standardisation Institute related to navigational radar devices in inland waters (ETSI, 2006). The standards presented both requirements and testing methods. The fact deserves attention that they do not give guidelines for tracking targets, which is why it can be concluded that it is not required at all in river radar. On the other hand, there are relatively high demands related to measurement accuracy of targets' position and discrimination. The document mentioned does not exclude, however, the possibility of enriching radar by additional software, which is why manufacturers frequently apply „tracking overlays" on the radar, where the tracking accuracy approximates marine tracking systems.

There are definitely more requirements for tracking devices within the scope of VTS systems. International tracking and tracing standards recommend that dynamic data in the VTS should be delivered with various accuracies for particular services in accordance with Table 1.

At the same time these documents indicate that the radar remains the basic source of navigational information, stressing the considerably rising role of AIS, which is able to improve significantly the quality of data acquired about the targets. As the work of the expert group was concentrated above all on preparing new AIS standards for inland waters, however, it seems justified in the Regulation of the European Commission to refer to IALA documents, which is the institution to set down VTS standards. In 2001 there appeared IALA guidelines pertaining to VTS systems in inland, which subsequently became the resolution of the European Economic Committee at the UN (UNECE, 2005), and were also adapted by the CCNR (CCNR, 2006). There was included general information on creating vessel management systems in inland waters, for more detailed guidelines it being referred to, *inter alia,* IALA requirements for devices used in VTS systems, V-128. This document has lived to a few editions, the latest of which (3rd version) appeared in 2007 (IALA, 2007).

IALA guidelines related to devices in systems of VTS traffic control were divided into a few sections, in which various appliances are described. Three various accuracy levels were introduced for all of them (basic,

Table 1. Accuracy requirements for dynamic data in VTS.

Service	Position (m)	SOG (km/h)	COG (°)	True course (°)
Navigation in short time	10	1	5	5
VTS assistance	10	1	5	5
VTS traffic manag.	10	1	5	5
Lock operation	1	0,5	3	
Bridge operation	1	0,5	3	

standard and extended) bearing in mind economic and technological indexes.

According to IALA guidelines, radar devices are the basic source of navigational information. Because of the specificity of each VTS system (surface shape, traffic density, economic factors, number of radar stations etc.) IALA recommends that the competent authority for a given VTS should lay down individually the requirements for tracking in each system, at the same time giving approximate reference values for a single coastal radar station (IALA, 2007). They were divided into three accuracy levels: basic, standard and advanced. In the last two, the permissible errors of course and speed determination are 2° and 1 knot, laid down on the level of one standard deviation (assuming Gaussian distribution), for a target moving at uniform motion.

What seems interesting is the status of television cameras in the RIS concept, and also VTS. Analysing Regulation 414/2007 it can be noticed that the CCTV camera is mentioned as one of the sensors providing information on traffic on an inland waterway; on the other hand, as it does not appear in any other place in the regulation, its role remains actually unknown. The Tracking and Tracing Expert Group does not mention the camera at all, concentrating on AIS. Only IALA devotes in their recommendations a little more room to CCTV television, but still moving about on a very general level. The camera is indicated there as a potential cheaper than radar source of information about targets in the VTS system. It can fulfil the role of a separate sensor, or supplement information acquired from radar with additional data, like the ship's name or kind. The camera is presented as a good method of supplementing radar coverage in a VTS area. The possibility is admitted that the camera may track targets on its own, but first of all its identification role is highlighted. The camera may show what the radar does not see, e.g. the kind of vessel or danger. Exact requirements are given with regard to the identification function, but there are none such concerning tracking. The only hint is the statement that in the scope of reliability, accuracy, range and resolution a system of industrial television has to meet the requirements of VTS system and expert organisations in the realm of graphics. In this case, the concept of tracking seems to take on a meaning from computer graphics, strictly speaking from computer vision, where tracking means following something and continuous monitoring something rather than determining its movement parameters. Nevertheless, the camera remains one of the sensors that can be used in the VTS system as a source of information about movement and target.

6 RECAPITULATION

The article characterises the subject matter of tracking surface water vessels in RIS systems. This is a problem many international organisations have been preoccupied with in recent years and the European Commission has in some way "dotted the i's and crossed the t's" by issuing directives in the RIS matter. Fortunately, the organisations mentioned cooperated with one another by mostly accepting solutions worked out in common. In their light, as the basic sources of information about vessels in the RIS system there appear Inland AIS, tracking radar and the vision camera within the framework of CCTV industrial television network.

An unquestioned leader in this area is the AIS system, whose introduction, also into inland waters, has opened a completely new chapter in the history of water traffic control. Its indications, assuming the correct functioning of the system, are clearly the most accurate. The radar system, though theoretically still the basis for tracking targets, ceases to be attractive, not only because it gives a less accurate position than GPS, but also because it provides significantly less useful information than AIS. The camera in turn is a short-range sensor, and its application for vessel movement vector estimation is practically unusual. Therefore, only the linking of both sensors into one complementary system gives hope that it will be up-to-date and face the challenges of modern times. What is more, such a system will have basic advantage over the AIS system, namely it will be independent from ship sensors and therefore, the RIS operator will have full control over it. AIS is based, after all, on information delivered by other vessels, and so, in case of their improper functioning, it gives erroneous values. The method of combined tracking based on radar and the camera seems to be a natural attempt at "unification" of these two sensors in order to meet the requirements set for modern tracking systems.

What seems most reasonable is making use of all mentioned sensors for tracking targets in RIS, which leads towards multi-sensor fusion of navigational data.

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9.5
Six in one or one in six variants. Electronic navigational charts for open sea, coastal, off-shore, harbour, sea-river and inland navigation

A. Weintrit
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: In the paper the author tries to explain problems connected with utilization of the GIS (Geographic Information System) technology and more sensitively speaking its waterborne implementation, ie. the ECDIS (Electronic Chart Display and Information System) technology and the electronic navigational charts (ENC) in the widely comprehended maritime (open sea, coastal and harbour) and inland navigation which the author does not limit exclusively to river-reservoirs only, but widens also for channels, navigable lakes and areas which can be defined generally as sea-river navigation areas. In the paper author presents the classification of the electronic navigational charts, primary functions and performance standards for electronic chart systems for open sea, coastal, off-shore, harbour, sea-river and inland navigation.

1 INTRODUCTION

An electronic chart system, whether an Electronic Chart Display and Information System (ECDIS) or an Electronic Chart System (ECS), is primarily designed for safe navigation. But its ability to display information selectively and relate it spatially is considered a real-time GIS application in the water environment. This paper describes the potential of ECDIS for maritime, coastal, offshore and inland applications.

Information technology has significantly changed the concept of navigation, the introduction of the latest computers and communication capabilities facilitating communication with sea-going vessels on the battlefield. Networking shipowners, vessel traffic service centres, river information systems, and individual vessels in ocean, coastal and inland navigation is carried out with the latest state of-the-art technology in computers and efficient communication network systems and e-Navigation.

Most cartographic research relating to the use of “soft copy” display considered the simple reproduction of conventional charts, maps and mapping techniques on CRT devices. Although the resolution of the screen is the immediately noticeable difference between the paper and the video display medium, it is not the most important factor influencing the quality of the display. The value of the electronic chart’s development is not in simply imitating the paper nautical chart, but in providing a dynamic display which successfully combines the real-time location of the ship with radar/ARPA/AIS returns and chart information. To maintain the visual simplicity of this more complex display, the data format, organization and type of chart features shown, and the way they appear on the screen, must reflect the relative importance of the information to safe navigation. Unlike the static paper chart, the electronic chart can change the display and emphasis of symbols, based on actual real-time events and the viewing scale chosen. The computer-based algorithms of the electronic chart allow it to always include the least number of symbols which are most relevant to a given situation. This paper describes the different types of electronic charts and electronic chart systems.

2 ELECTRONIC CHART SYSTEM AND ECDIS

The electronic chart system is a relatively new technology that provides significant benefits in terms of navigation safety and improved operational efficiency. More than simply a computer display, an electronic chart is a real-time navigation system that integrates a variety of information that is displayed and interpreted by the navigator. It is an automated decision aid capable of continuously determining a vessel’s position in relation to land, charted objects, aids-to-navigation, and unseen hazards. The electronic chart represents an entirely new approach to maritime navigation. There are two basic types of electronic chart systems. Those that comply with the IMO requirements for SOLAS class vessels, known as the Electronic Chart Display and Information System (ECDIS), and all other types of electronic chart systems, regarded generically as, Electronic Chart Systems (ECS).

ECS encompasses any electronic system that uses digital chart data. There are standards being developed for ECS by the ISO and earlier by the Radio Technical Commission for Maritime Services. ECDIS is system that is certified to meet a suite of international standards: IHO Transfer Standard for Digital Hydrographic Data S-57, IHO Specifications for Chart Content and Display aspects of ECDIS S-52, IMO Resolution A.817(19) Performance Standards for ECDIS,

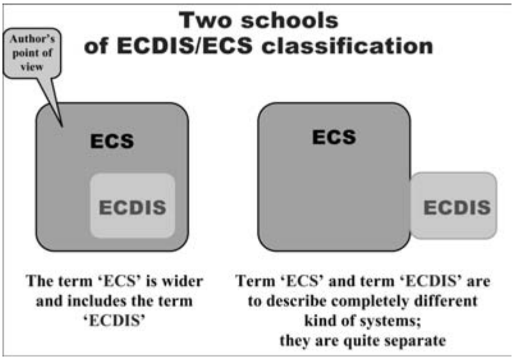


Figure 1. Two schools of ECDIS/ECS classification.

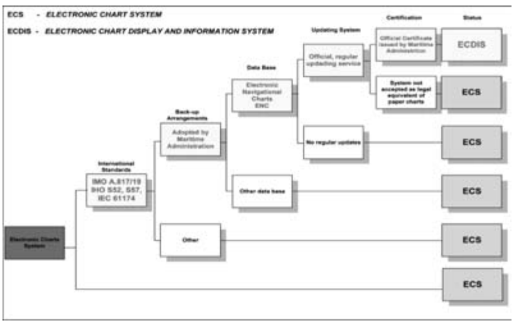


Figure 2. Classification scheme for electronic charts systems pretending to internationally standardised name of Electronic Chart Display and Information Systems (ECDIS) (Weintrit, 2001, 2009).

and IEC 61174: ECDIS – Operational and performance requirements, methods of testing and required test results. An ECDIS must use "official" ENC data to meet all of these standards and may use "official" raster data where ENC data is not yet available.

It is important to lay to rest right at the start the difference between ECS and ECDIS. In simple terms, an ECDIS is an ECS but an ECS is not necessarily an ECDIS! Confused? Let's try to explain.

Any ECS is a navigation system utilising computers and other electronic systems to plot and track a vessel's position. It will consist of, at least, a central computer, a library of electronic charts, a position input such as Global Positioning System (GPS) and a display screen. The electronic charts stored in the library may be in either raster or vector formats and they may be official or unofficial charts.

ECS cannot be the legal equivalent of the paper navigational chart (since it does not meet all the IMO, IHO and IEC standards for ECDIS), is already in widespread use around the world, and is characterised by being physically smaller, less sophisticated, and less expensive than fully compliant ECDIS. ECS displays different types of chart data (vector or raster) provided by hydrographic office, commercial manufacturer or user. It is intended for the use in conjunction with a current, updated paper chart. It cannot function as an ECDIS system since it does not meet the IMO standards for equipment which is a legal substitute for paper charts.

The true ECDIS system displays information from electronic navigational charts (ENC) and integrates position information from the GPS/GNSS and other navigational sensors, such as radar/ARPA, echosounder and automatic identification systems (AIS). It may also display additional navigation-related information, such as Sailing Directions, Tide Tables, etc. The ENCs themselves are as important as the system that displays them. Again confusion sometimes exists between official ENCs which have to be produced by or on behalf of a government authorised Hydrographic Office, and other commercial electronic charts which, whilst they may be able to be displayed on an ECDIS system, do not comply with the IMO regulations for use as the primary navigational chart system.

Only when official ENCs are run in a compliant ECDIS system can it be called an ECDIS. All other chart data used immediately downgrades the system to an ECS, and non-compliant, under the terms of the SOLAS regulations for use of Electronic Charts as a primary means of navigation for merchant shipping. This distinction is often over-looked by would be purchasers, but those lawyers may not be quite so ready to ignore the regulations.

ECDIS equipment is specified in the IMO ECDIS Performance Standards (IMO Resolution A.817(19), as amended by Resolution MSC.64(67) – Adoption of New and Amended Performance Standards (adopted in 1996), Annex 5 – Amendment to Resolution A.817(19) Performance Standards for ECDIS; as amended by Resolution MSC.86(70) – Adoption of New and Amended Performance Standards for Navigational Equipment (adopted in 1998), Annex 4 – Amendments to the Recommendation on Performance Standards for ECDIS; and as amended by Resolution MSC. 232(82) – Adoption of the Revised Performance Standards for ECDIS (adopted in 2006), Revised Performance Standards for ECDIS as follows: "Electronic chart display and information system (ECDIS) means a navigation information system which, with adequate back up arrangements, can be accepted as complying with the up-to-date chart required by regulation V/19 and V/27 of the 1974 SOLAS Convention, as amended, by displaying selected information from a system electronic navigational chart (SENC) with positional information from navigation sensors to assist the mariner in route planning and route monitoring, and by displaying additional navigation-related information."

Within the ECDIS, the ENC database stores the chart information in the form of geographic objects represented by point, line and area shapes, carrying individual attributes, which make any of these objects unique. Appropriate mechanisms are built into the system to query the data, and then to use the obtained information to perform certain navigational functions (e.g. the anti-grounding surveillance).

Table 1. Electronic navigational charts versus paper charts.

Paper Chart	Electronic Chart
fixed scale sheet, fixed North-up orientation (usually), fixed symbol definition, fixed symbol arrangement and application with respect to North, limited paper size, limited types and amount of information, limited number of colours and combined use.	fixed display size, fixed resolution, variable display scale, variable types and amount of information, various orientation with respect to North, various symbol arrangement and application, various symbol definition, various number and use of colours.

The presentation of ENCs on the screen is specified in another IHO standard, the "Colours and Symbols Specifications for ECDIS IHO S-52", i.e. in its Appendix 2, called "ECDIS Presentation Library". This style of presentation is mandatory.

The use of ENCs in a tested approved and certified ECDIS (according to IEC 61174/2008) and with appropriate back up arrangements, is the only paperless chart option for vessel navigation.

3 ELECTRONIC NAVIGATIONAL CHART

An Electronic Navigational Chart (ENC) is a digital representation of the paper charts, a digital file that contains all the chart information necessary for safe navigation, as well as supplementary information required to plan voyages and avoid groundings (route planning and route monitoring).

ENC boasts electronic features that paper charts lack. For instance, a navigator can integrate GPS data – which tells a navigator his or her precise latitude and longitude – with ENC data. The navigator can also integrate data from Geographic Information Systems (GIS), real-time tide and current data, and wind data to enhance the capabilities of the ENC.

Incorporating these features can create a fuller, more accurate picture of the marine environment. A vessel using ENCs can detect an obstruction in advance and check planned travel routes to avoid crossing hazardous areas. The electronic charting systems used to view ENCs can display warnings and regulations that pertain to areas in which a vessel transits, and can sound an alarm if the vessel's projected course veers too close to a dangerous feature.

3.1 *Types of electronic charts*

3.1.1 *Vector charts*

Vector charts are the chart databases for ECDIS, with standardized content, structure and format, issued for use with ECDIS on the authority of government authorized hydrographic offices. ENCs are vector charts that also conform to International Hydrographic

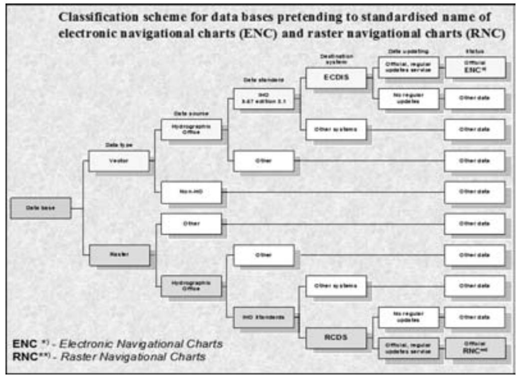


Figure 3. Classification scheme for data bases pretending to internationally standardised name of electronic navigational charts (ENC) and raster navigational charts (RNC) (Weintrit, 2001, 2009).

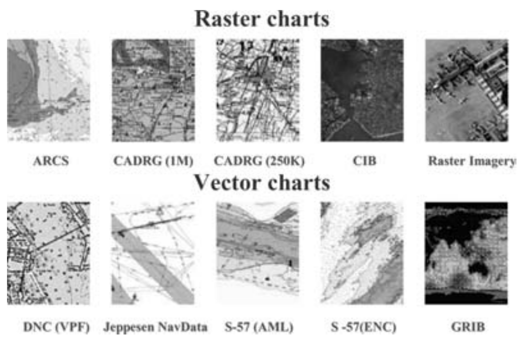


Figure 4. Various types of raster and vector charts.

Organization (IHO) specifications stated in Special Publication S-57.

ENCs contain all the chart information necessary for safe navigation, and may contain supplementary information in addition to that contained in the paper chart. These supplementary information may be considered necessary for safe navigation and can be displayed together as a seamless chart. ENCs are intelligent, in that systems using them can be programmed to give warning of impending danger in relation to the vessel's position and movement.

3.1.2 *Raster charts*

Raster navigational charts are raster charts that conform to IHO specifications and are produced by converting paper charts to digital image by scanner. The image is similar to digital camera pictures, which could be zoomed in for more detailed information as it does in ENCs. IHO Special Publication S-61 provides guidelines for the production of raster data. IMO Resolution MSC.86(70) permits ECDIS equipment to operate in a Raster Chart Display System (RCDS) mode in the absence of ENC.

Not all electronic charts are in same format; many different formats exist for electronic charts. However, two major types are now in use on merchant ships,

Table 2. The differences between raster charts and vector charts.

Raster Chart (RNC)	Vector Chart (ENC)
Chart data is a digitized "picture" of a chart. All data in one layer and one format.	Chart data is organised into many separate files. It contains layer information to produce certain symbols, lines, area, colours, and other elements.
With raster data, it is difficult to change individual element of the chart since they are not separated in the data file.	With vector data, it can change individual elements with additional data.

they are vector chart and raster charts. Raster charts (RNC), in fact, are scanned paper charts into the pictures with adjustment made suitable for display on the RCDS. This RNC is also known as Admiralty Raster Chart System (ARCS Charts) which is produced by the British Admiralty (UKHO).

Vector charts are digitized charts. Countries are producing unique digital charts based on their interpretation of IHO standards (i.e. S-57 standards).

4 CONFUSION OVER THE CHARTS

The by far major problem in the use of ECDIS lies in the charts to be used. The confusion appears to be complete amongst shipping lines and chart distributors and even among the various authorities around the world. You must use an ENC in order to use the system as an ECDIS. If no complete ENC coverage is available for the ships area of operations you have to use other available charts, and then your system turns into an ECS.

The ENC coverage was at this point in time very limited, and it was difficult to get an overview over which parts of the world that are covered by ENCs. It was merely stating the fact that the availability of ENCs was limited, and thus the possibility to use ECDIS in practice was limited. The confusion begins, when we start speaking about other types of charts than ENCs, in particular RNCs.

4.1 *Non-official charts*

There is a number of alternatives to the aforementioned ARCS charts. E.g. Transas and C-Map have almost worldwide coverage of vector charts where the data is based on existing paper charts. Unfortunately these charts have not obtained the status as official, because of the frequency of the updates and the lack of a controlling authority to approve the contents.

How big a part of the scales is weighed by these facts more or less depends on the flag of the ship and thus the flag state administration. The obvious advantage by using C-Map charts is therefore in the available safety features, which are inherent in the vector charts.

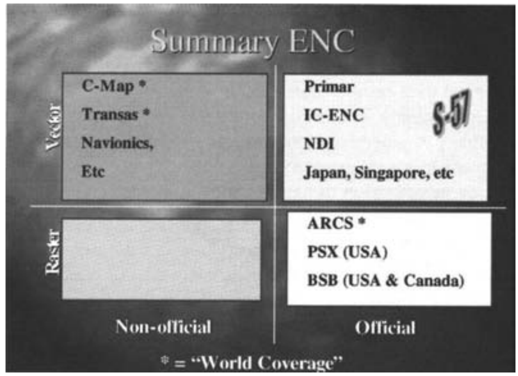


Figure 5. Summary of ENCs (Arts, 2003).

4.2 *Data from private data providers*

Examples of raster navigational chart producers are: NOAA, Maptech, SoftChart and Laser Plot in the United States, NDI in Canada and British Admiralty (ARCS) in England. Vector marine charts for chart plotters are produced by C-Map and Navionics. Garmin's MapSource BlueChart and Magellan's MapSend BlueNav charts are derived from Navionics vector charts. Other vector marine charts come from Passport and Transas.

If it is so expensive to produce and update ENCs, how then have private companies succeeded in building what seems to be decent world coverage? Please let's not get involved in another discussion about the legality of their products; everyone knows that SOLAS, Chapter V regulation 2.2 states that 'Nautical chart or nautical publication is a special-purpose map or book, or a specially compiled database from which such a map or book is derived, that is issued officially by or on the authority of a Government, authorised Hydrographic Office or other relevant government institution and is designed to meet the requirements of marine navigation'. Therefore we know that only the ENCs produced by HOs may be used by commercial vessels of more than 500 GRT.

4.3 *Assessment standard ISO 19379*

In order to meet the requirement mentioned above an (international) standard for privately manufactured data was developed over the past ten years. The standard, ISO 19379, was prepared by Technical Committee ISO/TC8 (Ships and Marine Technology, subcommittee SC6, Navigation) and adopted in 2003.

ISO 19379 is the international standard that specifies the requirements for ECS databases, especially as regards the elements relevant to safety of navigation, such as content, quality and updating. The standard was developed by ISO (International Organization for Standardization), with the contribution of Hydrographic Offices, Classification Authorities, and the Marine Industry, and is being adopted by Maritime Administrations to regulate the use of ECS – in Italy, for example, it is part of the requirements for approved Electronic Chart Systems, which can replace paper charts on certain types of craft (Malie, 2003).

ISO 19379 provides guidance on production and testing of an ECS Database. It does not provide detailed coverage of the methods and techniques required for database design and development, nor does it address specific quality management procedures.

4.4 *Use of the standard*

The standard is applicable to both vector and raster charts. It is envisaged that national regulatory authorities may wish to require compliance with this standard as guidance for data used in ECS or other systems of electronic navigation in their countries. The Standard has been developed to make the ECS chart display as reliable as the official paper chart and its equivalent ENC. The aim of the working group has been to develop a standard easy to interpret but with content and accuracy levels at least equal to those of the ENC of the same area, carefully avoiding, however, any over-specification or rigid structure.

4.4.1 *Contents of the standard*

The contents of the chart are very much in line with the requirements as described in IHO S-52 (Specifications for Chart Content and Display Aspects of ECDIS, Dec. 1996).

4.4.2 *Quality*

This covers, among other items, product specification, process control and correctness and completeness of encoding.

4.4.3 *Updating*

This covers, among other items, the responsibility of the database producer to provide updates.

4.4.4 *Testing*

This covers the recommended methods of testing. Testing procedures shall ensure the accuracy and completeness of the entire data production process. The manufacturer may be required by national authorities or similar to have its testing procedures certified by an appropriate testing body. The standard does not prescribe a specific data format for privately manufactured data. Data producers are responsible for providing updates in their own format. A Performance Standard for ECS, including the display of data, was developed by the Radio Technical Commission for Maritime Services (RCTM). It should be noted, however, that some flag states have also individually developed Performance Standards for ECS.

4.5 *Filling the gap?*

In areas with no ENC coverage navigators have the choice either of using official raster data or privately manufactured vector data. No doubt the first option offers, next to the use of 'official' charts, the advantage that the number of paper charts carried may be considerably reduced, whereas the second requires a full set but retains full ECDIS functionality (including the alarm functions) that can only be obtained using vector charts.

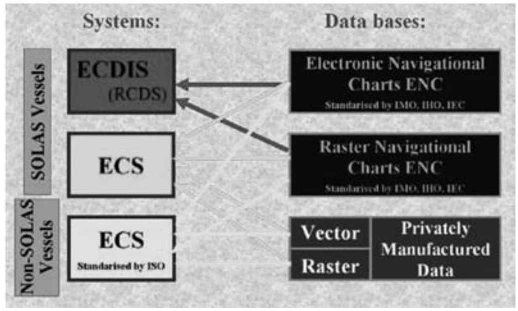


Figure 6. Relationship between electronic chart systems ECS/ECDIS and data bases (Weintrit, 2009).

4.6 *Instead of ENC?*

This option is at present preferred by several ship-owners, particularly those operating their ships globally. Although most ECDIS do support privately manufactured data produced by the major manufacturers, many users prefer (for cost reasons) ECS, particularly as many of these systems nowadays (also) meet the software requirements laid down in IEC 61174 (ECDIS Operational and Performance Requirements) and are less expensive. In this case, of course, paper charts are used for primary navigation. The time consuming (IMO) mandatory passage planning however can be done using the ECS and, where applicable, copied to the paper chart.

4.7 *ENC and the private data manufacturer*

As mentioned before, there is no doubt that the number of ENCs will increase with time. Although still expensive compared with privately manufactured vector data, prices have come down considerably recently. This may move the market to purchase more ENC. Most helpful will be the support of private manufacturers in acting as value-added re-sellers and in providing ENC in SENC format. No doubt they will be keen to 'fill the gap' with their own data if necessary.

4.8 *Replacing paper charts*

National authorities could consider accepting privately manufactured data meeting ISO 19379 as paper chart equivalent for certain (non-SOLAS) vessels. The US and Italian governments have already amended the law to allow fishing vessels and leisure craft fitted with ECS and electronic navigational data that meets the ISO standard, to sail without paper charts in their waters.

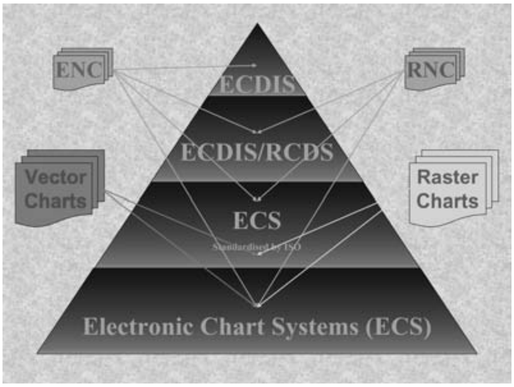


Figure 7. Relationship pyramid between electronic chart systems ECS/ECDIS and data bases (Weintrit, 2001, 2009).

4.9 *IMO MSC approved mandatory ECDIS*

In July 2008, the IMO Safety of Navigation Sub-Committee agreed to implement the mandatory carriage of ECDIS; this was approved by the IMO Maritime Safety Committee at its meeting in December 2008.

A comprehensive phase-in schedule will begin on 1 July 20–12 with mandatory carriage of ECDIS for newbuildings of passenger ships of 500 gt and above and for tankers of 3000 gt and above.

Mandatory carriage for existing ships will be phased in from 1 July 2014 to 1 July 2018.

5 INLAND ECDIS

ECDIS is the basic system for generation and presentation of the digital maritime charts. Charts based on the maritime standards are officially equal to analogic charts in equipment duties. Within European research and development projects, this world-wide standard was adopted to the needs of inland navigation. The Inland ECDIS standard has been continuously revised and finally passed by the Central Commission for the Navigation on the Rhine (CCNR) in summer 2001. Inland ECDIS is also recommended as the standard for digital navigational charts by the Danube Commission, the United Nations' European Commission for Economy (UN-ECE), the European RIS platform and INA/PIANC. Inland ECDIS is currently the only standard accepted by all relevant inland navigation platforms. Co-operation between the North-American "Inland ENC community", mainly the US Army Corps of Engineers, Russia and the (European) Inland ECDIS Expert Group lead to improved and harmonized encoding rules for uniformly encoded Inland ENCs, which are written down in the "Inland ENC Encoding Guide".

5.1 *European inland waterways*

Europe is criss-crossed by inland waterways, some of which have been in use for thousands of years to carry goods and people. The most recent addition to this network, the Rhine-Main-Danube Canal, was finished in 1992 and opened a 3,500 km long trans-European waterway from Rotterdam to Sulina on the Black Sea. Many people do not realise that cargo brought by ship to Le Havre can then be delivered by an inland vessel to Basel or to a port in Poland or in Moldova. The inland waterways traffic, almost invisible to the population, is the most efficient way to carry heavy goods over long distances.

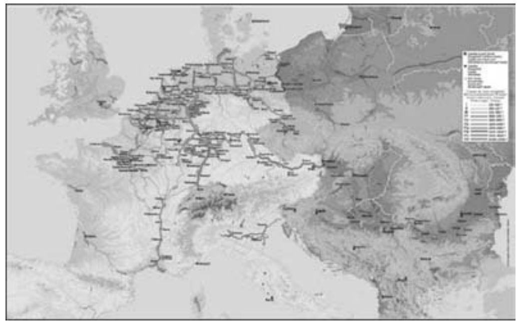


Figure 8. Main European waterways.

5.2 *Electronic chart display and information system for inland navigation*

Reflections and experiments have been made in different countries with a view to facilitating inland navigation through the use of telematics. This aim was in particular pursued within the scope of the EU research and development project INDRIS (Inland Navigation Demonstrator for River Information Services). A pilot project on the river Rhine was launched in Germany in 1998 named ARGO. In ARGO and INDRIS systems, the radar image on the display in the wheelhouse is overlaid by an electronic chart. This is an approach aimed at improving safety and efficiency in inland navigation.

In the course of discussions, it turned out that only an internationally-agreed approach would be successful, since a boat master cannot be expected to employ different equipment in each country. This was the reason why the internationally-introduced ECDIS – originally developed for maritime navigation – came into view also for inland navigation. The IMO, IHO and IEC Standards for ECDIS were introduced in their compatibile versions in 1996 (latest versions between 2006 and 2008). The idea was to adopt ECDIS for inland navigation and to supplement some distinct inland features but not to change the original ECDIS standard. In this way, it will be possible to have compatibility between the original – Maritime – ECDIS and Inland ECDIS. This is important for the estuaries of the rivers, where sea vessels as well as inland vessels navigate.

In the framework of the concerted action on Inland Navigation of the European Union, an International Expert Group was requested to prepare the Inland

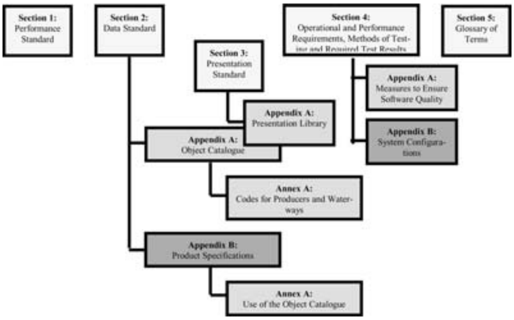


Figure 9. Structure of the Inland ECDIS standards.

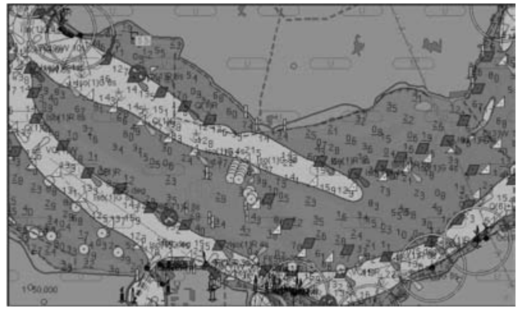


Figure 10. Simplified symbols of Sea-River and Inland Electronic Navigational Chart.

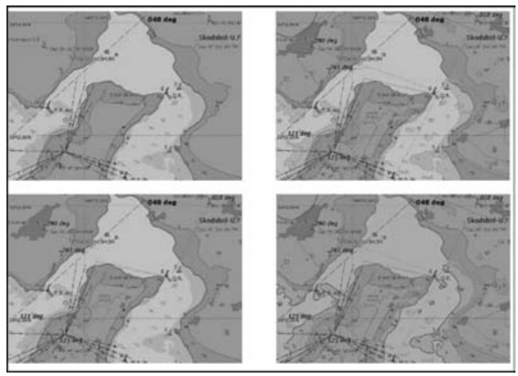


Figure 11. Display Base, Standard Display, and Full Displays for two different values of Safety Contour – SeeMyDENC.

ECDIS Standard intended especially for inland navigation. The Inland ECDIS standard adopts the regulations of the maritime ECDIS and adds requirements to it that are specific to inland navigation. The Central Commission for the Navigation on the Rhine (CCNR) passed the Inland ECDIS standard in May 2001. The standard consists of the following Sections (very similar to ISO 19379):

- Section 1: Performance Standard;
- Section 2: Data Standard;
- Section 3: Presentation Standard;
- Section 4: Operational and Performance Requirements, Methods of Testing and Required Test Results;
- Section 5: Glossary of Terms.

The Inland ECDIS Standard establishes unified rules for the use of electronic charts by vessels navigating on European inland waterways.

5.3 *Primary functions and performance of I-ECDIS*

Inland ECDIS shall contribute to safety and efficiency of inland shipping and thereby to the environment protection. It shall reduce the navigational workload as compared to traditional navigation and information methods.

Inland ECDIS (Operating System Software, Application Software and Hardware) shall have a high level of reliability and availability at least of the same level as other means of navigation, for the navigation mode as specified in Section 4 of the standard. Inland ECDIS can be designed for information mode only or for both, information mode and navigation mode. It shall use chart information as specified by Sections 2 (Data Standard) and 3 (Presentation Standard) of the mentioned Standard.

The Data Standard for Inland ECDIS is based on the “IHO Transfer Standard for Digital Hydrographic Data”, Special Publication No. 57, edition 3.1 of November 2000 with all Appendices and Annexes. The Data Standard describes the necessary additions and clarifications to S-57 and the application of S-57 for the purpose of use in Inland ECDIS applications.

The Presentation Standard for Inland ECDIS is based on the document “S-52, Specification for Chart Content and Display Aspects of ECDIS” of the IHO, Edition 5.0 of December 1996, with all Appendices and Annexes. Inland ECDIS shall facilitate simple and reliable updating of the Inland ENC. It shall provide appropriate alarms or indications with respect to the information displayed or malfunction of the equipment.

5.4 *I-ECDIS related definitions*

For the Inland ECDIS performance standard the following definitions shall apply:

- Inland ECDIS means an electronic chart display and information system for inland navigation, displaying selected information from an Inland System Electronic Navigational Chart (Inland SENC) and, optionally, information from other navigation sensors.
- Inland Electronic Navigational Chart (IENC) means the database, standardized as to content, structure and format, issued for use with Inland ECDIS. The Inland ENC complies with the IHO standards S-57 and S-52, enhanced by the additions and clarifications of this standard for Inland

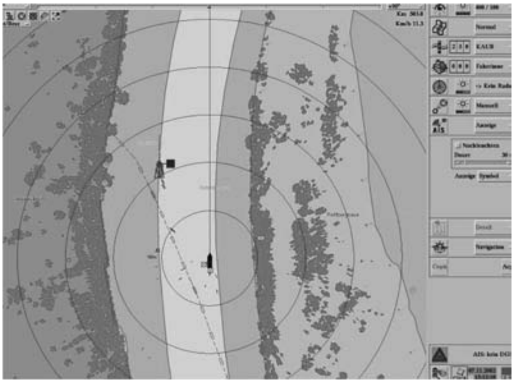


Figure 12. Inland ENC with radar picture overlay; North-up orientation of ECDIS.

ECDIS. The Inland ENC contains all essential chart information and may also contain supplementary information that may be considered as helpful for navigation.

- Inland System Electronic Navigational Chart (Inland SENC) means a database, resulting from the transformation of the Inland ENC by Inland ECDIS, for appropriate use, updates to the Inland ENC by appropriate means and other data added by the boat master. It is this database that is actually accessed by the Inland ECDIS for the display generation and other navigational functions. The Inland SENC may also contain information from other sources.
- Minimum Information Density (display base) means the minimum amount of SENC information that is presented and which cannot be reduced by the operator, consisting of the information that is required at all times in all geographic areas and under all circumstances.
- Standard Information Density (standard display) means the default amount of SENC information that shall be visible when the chart is first displayed on Inland ECDIS.
- All Information Density (all display) means the maximum amount of SENC information. Here, in addition to the standard display, also all other objects are displayed, individually on demand.
- User-defined settings means the possibility to use and store a profile of display- and operation controls-settings.
- Integrated Display means a head-up, relative-motion picture consisting of the SENC overlaid with the radar-image with matching scale, offset and orientation.
- Navigation Mode means the use of the Inland ECDIS for conning the vessel with overlaid radar image.
- Information Mode means the use of the Inland ECDIS for information purposes only without overlaid radar image.

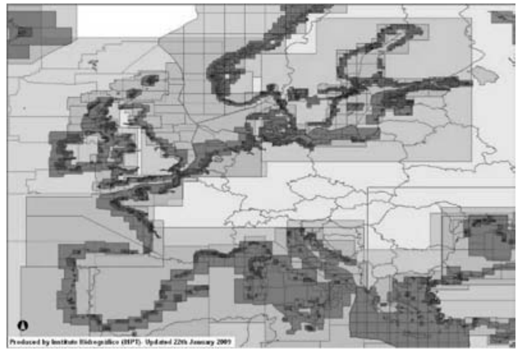


Figure 13. IC-ENC catalogue – Europe 22th January 2009.

5.5 *Benefits of I-ECDIS*

The inland navigation software based on the SevenCs Kernel is in use all over the world. In Europe alone, some 2,800 inland vessels use it already (Gevers, 2006). The acceptance of the electronic charts by the inland skippers is not surprising, even allowing for the fact that electronic charts are not a carriage requirement for them. Electronic charts improve the safety of navigation and the efficiency of operation of the inland vessels leading to reduced costs and improved earnings. For instance, the North American skippers who use the course predictor built into the SevenCs software to prevent oversteering of their enormous barge trains, report fuel savings of up to 10%. In addition, Inland ECDIS is not labouring under the same regulatory restriction as its maritime sister. The functionalities that are already provided to inland but not to sea navigation include dynamic depth and overhead clearance adjustment or changes of channel width depending on the water level; display of the external XML files with additional information will follow in the near future.

On US waterways much more popular is CARIS' Hydrographic Production Database (HPD). The production effort focused on importing IENC data into a HPD source database, which was easily accomplished due to existing S-57 import tools. Once loaded, the source data was modified to create a seamless coverage ready for further production.

5.6 *Seamless connection*

Inland port authorities have recognised the fact that electronic charts improve their efficiency of operation as well and are supporting the production of the IENCs. The importance of inland ports like Duisburg can only increase, especially as many major seaports are experiencing a growing need to cope with overflowing ports, Rotterdam which is running out of space for its expansion being one of them. Seagoing vessels have been sailing up many large rivers for a long time, on all continents. The best example is the Mississippi, where Baton Rouge some 230 miles upstream, is a major seaport as well as an inland port. The needs of the inland navigation are not the same as those of the sea-going ships, but there are many areas where both types of vessels have to ply. Inland ECDIS and IENCs create a seamless connection between these two worlds.

5.7 *Facilitating the use of ENC on us inland waterways*

In 2001, the US Army Corps of Engineers (USACE) initiated an electronic chart program to develop and support new digital chart products for electronic navigation on the inland waterways. The program began by transforming existing digital river data and digital chart data into a new product: the Inland Electronic Navigational Chart (IENC).

Updating navigational charts, whether paper or electronic, is an essential safety element for any vessel. Numerous changes regularly occur in the river system, including channel dredging, construction, navigation aid maintenance and natural variations in the river bottom. Once significant changes occur, a new edition chart is often published. Currently, the IENC program is producing new edition electronic charts and updating them at faster pace than former paper chart program, where chart editions can be 5-to-10 years old and updates must be applied manually.

A number of potential opportunities and benefits are possible with CARIS' HPD used by USACE. First, retaining a close link between the source data and the paper chart products can significantly facilitate data maintenance and timely or simultaneous product releases. It can also facilitate closer synchronization between IENC and paper chart formats, resulting in improved consistency and version control across the entire product line.

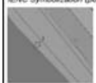
HPD-driven approach provides improved production workflow, many more advanced tools for paper chart production and better support for the cartographic framework. It also allows for a far greater level of automation, ultimately reducing manual effort. Consequently, it is more suitable for large, long term projects.

5.8 *Usace inland ENC encoding guide*

IENCs follow the S-57, Version 3.1 data exchange standard, which is recognized by software vendors and government hydrographic offices for electronic chart applications. Since S-57 is intended for deep-draft, ocean shipping, the US Army Corps of Engineers (USACE) IENC Encoding Code provides a "best fit" in some cases between river information and S-57 structure. The intent of the Encoding Guide is to provide detailed guidance on what is required to produce a consistent, uniform Inland ENC. This document provides a framework for IENC specifications by:

- Using existing IHO S-57 Edition 3.1 standard. Specifically, the:
  - Maritime ENC Product Specification (App. B1),
  - IHO Object Catalogue (Appendix A),
  - Object Catalogue (Appendix B.1, Annex A),

Table 3. Inland ENC Encoding Guide. Example of geographic object.

Graphics	Encoding Instructions	Object Encoding
Real World  *Chart Symbol* *Image to be included at a later date* *IENC Symbolization (point)*  *IENC Symbolization (area)* 	A) Only visually conspicuous landmarks shall be encoded as landmarks. As a result the mandatory attribute CONVIS shall always be 1 (visually conspicuous). B) Castles, churches, chapels and transmitters can be encoded as CATLMK = 17 (tower), but then the type must be further made clear within the object name. C) If the landmark serves as a navigational light support, FUNCTN = 33 (light support), it must be encoded with a LIGHTS object (see N). D) If the landmark has a navigational function it has to be encoded as a building of navigational significance (see E.1.2).	Object Encoding **Object Class =** LNDMRK(P, A) (M) CONVIS = [1 (visually conspicuous)] (M) CATLMK = [1 (cairn), 2 (cemetery), 3 (chimney), 4 (dish aerial), 5 (flagstaff/flagpole), 6 (flare stack), 7 (mast), 8 (wind sock), 9 (monuments), 10 (column/pillar), 11 (memorial plaque), 12 (obelisk), 13 (statue), 14 (cross), 15 (dome), 16 (radar scanner), 17 (tower), 18 (windmill), 19 (windmotor), 20 (spire/minaret), 21 (large rock or boulder on land), 22 (rock pinnacle)] (O) OBJNAM = [name and/or operator/owner] (O) NOBJNM = (Refer to Section B, General Guidance) (C) FUNCTN = [33 (light support)] (M) SCAMIN = [EU: use 22000 for a point object (except 45000 for CONVIS1) and 45000 for line objects; US: 60000] (C) SORDAT = [YYYYMMDD] (C) SORIND = (Refer to Section B, General Guidance)

- Defining the mandatory requirements for safety-of-navigation on inland waterways.
- Recommending object classes, attributes, and values for encoding IENC data.

For all object classes, attributes, and attribute values that are used in conjunction with an IENC, the Encoding Guide:

- provides a basis for its creation,
- describes its relationship to the real-world entity,
- provides criteria for its proper use,
- gives specific encoding examples.

6 DIFFERENT TYPES OF DIGITAL CHARTS

6.1 *Electronic Navigational Chart (ENC) according to IHO format S-57*

An electronic navigational chart (ENC) is an official database created by a national hydrographic office for use with an Electronic Chart Display and Information System (ECDIS). An electronic chart must conform to standards stated in the International Hydrographic Organization (IHO) Special Publication S-57 before it can be certified as an ENC. Only ENCs can be used within ECDIS to meet the International Maritime Organisation (IMO) performance standard for ECDIS.

It is quite obvious that an official ECDIS service cannot be provided on a national level only, but requires co-operation of hydrographic services. The IHO decided to establish the Worldwide Electronic Navigational Chart Data Base (WEND).

ENCs are available through Regional Electronic Navigational Chart Coordinating Centre (RENCs) and national electronic chart centers: e.g. Primar-Stavanger (perfect seamless ENC cells), IC-ENC (British style ENCs). Distributors like the United Kingdom Hydrographic Office then distribute these to chart agents.

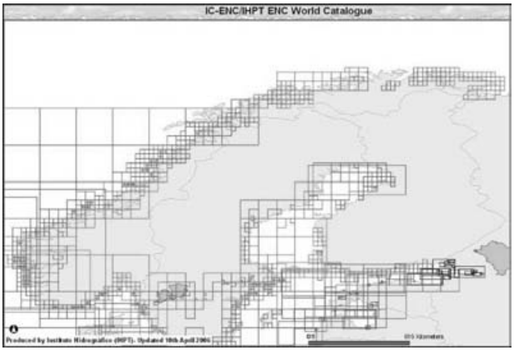


Figure 14. Norwegian (Primar) style seamless ENC cells.

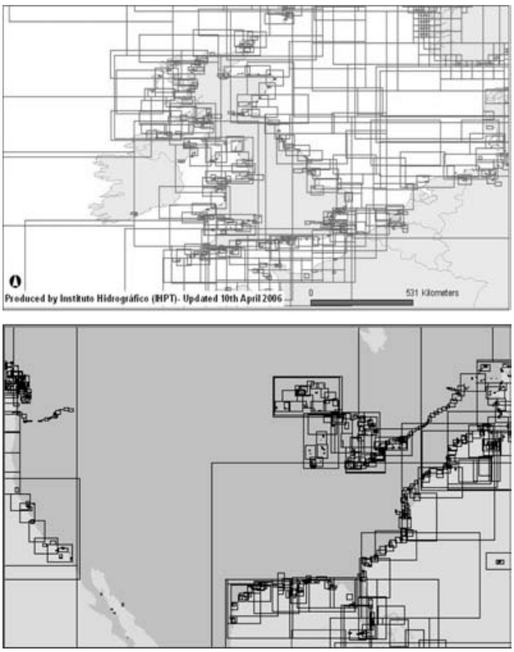


Figure 15 & 16. American/British style ENC cells.

IHO Special Publication S-63 developed by the IHO Data Protection Security Working Group is used to commercially encrypt and digitally sign ENC data. Chart data is captured based on standards stated in IHO Special Publication S-57, and is displayed according to a display format stated in IHO Special Publication S-52 to ensure consistency of data rendering between different systems.

6.2 *Vector chart produced by private manufacturer*

The existence of privately manufactured data is a fact of life. It is there, its volume is still increasing and it has proved to be meeting a demand of the maritime market. It is cost-effective, economically viable and it

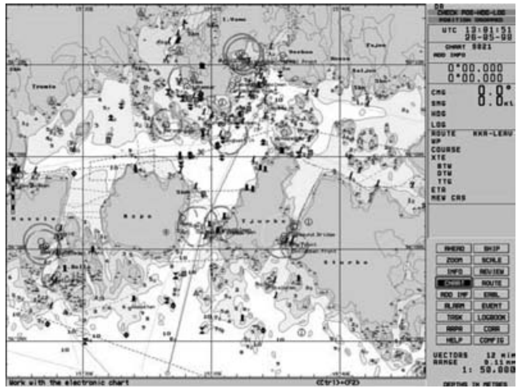


Figure 17. Transas electronic chart in vector format TX-97.

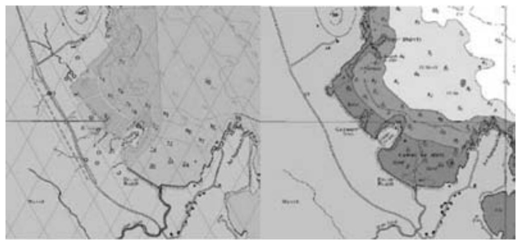


Figure 18. Additional Military Layers (AML).

will not disappear. The major data private manufacturers (e.g. Transas, C-Map by Jeppesen, Navionics) offer a high quality and affordable means of worldwide navigation, including an easy to access update service, sold through reliable global networks offering a round-the-clock service. There is no doubt that in the years to come the volume of ENC will increase. However, the production rate is still too slow to provide the (minimum) necessary coverage, particularly of the major shipping routes, in an acceptable time. Moreover, it is very unlikely that ENC will ever have a 100% global coverage.

6.3 *Electronic Navigational Chart (ENC) with additional military layers (AML) for WECDIS use*

The concept of additional military layers (AML) was introduced in 1995 with the intent to define a standardized format for non-navigational data. Since 1995, various North Atlantic Treaty Organization (NATO) standardization agreement documents concerning AML data and warship electronic chart display and information systems (WECDIS) have been created. NATO has since endorsed six AML product specifications, and completed sea trials using AML datasets. However, as more nations move toward AML data production, little is known about how the data will perform as overlays within a WECDIS adhering to NATO WECDIS standards.

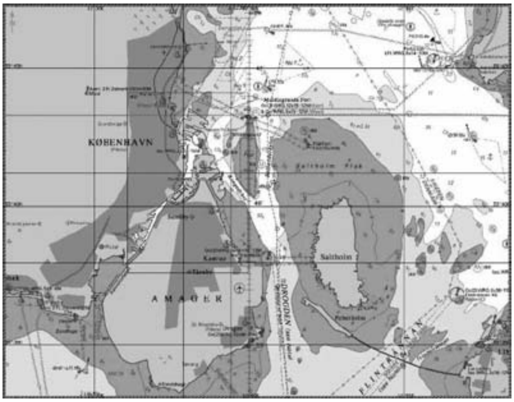


Figure 19. Raster Navigational Chart (RNC).

Figure 20. Coverage of seamless Inland ENC in NE Europe.

Using OSI Navigation Systems' electronic chart precise integrated navigation system-military (ECPINS-M), the sophisticated electronic chart system designed to meet the specific navigational demands of the military market, the strengths and weaknesses of how AML data interacts with other data types, primarily electronic nautical chart (ENC) data, within the WECDlS were identified. As stated in the WECDIS standard, a WECDIS means "an ECDIS as defined by the IMO, with additional functionality for navigation and conduct of warfare onboard warships." We might also consider referring to the concept of Marine Information Overlays (MIO) which have been used in the Marine Electronic Highway project, and whose use are gathering support within the e-Navigation discussion.

6.4 *Raster navigational chart (RNC)*

RNCs are raster charts that conform to International Hydrographic Organization (IHO) specifications and are produced by digitally scanning a paper chart image. The image may be either the finished chart itself or the stable colour bases used in the multi-colour printing process. The resulting digital file may then be displayed in an electronic navigation system where the vessel's position, generally derived from electronic position fixing systems, can be shown. Since the displayed data are merely a digital photocopy of the original paper chart, the image has no intelligence and, other than visually, cannot be interrogated.

6.5 *Digital Nautical Chart (DNC)*

The largest of the non-S-57 format databases is the Digital Nautical Chart (DNC). The National Imagery and Mapping Agency (NIMA, now National Geospatial-Intelligence Agency – NGA) produced the content and format for the DNC according to a military specification.

The DNC is a vector-based digital product that portrays significant maritime features in a format suitable for computerised marine navigation. The DNC is a general purpose global database designed to support marine navigation and Geographic Information System (GIS) applications. DNC data is only available to the U.S. military and selected allies. It is designed to conform to the IMO Performance Standard and IHO specifications for ECDIS.

6.6 *Offshore electronic navigational chart*

In offshore industry, such as Offshore Oil & Gas, Telecommunications, Fishing, Aggregate Extraction, Diving, sometimes are used three dimensional digital nautical charts 3DNCs. In Dynamic Positioning System are used ENCs. Few screens allow officers to switch screens between radar and chart displays, cameras from the closed circuit TV system, and the vessel's "Pilot"/"Harbour Approach" display.

6.7 *Inland electronic navigational chart (I-ENC)*

The goal of the North American – European Inland ENC Harmonization Group (IEHG), formed in 2003, is to agree upon specifications for Inland ENCs that are suitable for all known inland ENC data requirements for safe and efficient navigation for European, North and South American and Russian inland waterways. However, it is intended that this standard meet the basic needs for Sea-River and Inland ENC applications, worldwide. As such, the Sea-River and Inland ENC standard is flexible enough to accommodate additional inland waterway requirements in other regions of the world.

7 CONCLUSIONS

Electronic Navigational Charts have improved the safety of navigation and the efficiency of operations for US and Europe's Inland Mariners who have welcomed digital technology wholeheartedly.

Inland water transport is gaining the attention of the policy-makers. So let's go forward with I-ECDIS and Inland ENC (River ENC) and Sea-River ENC.

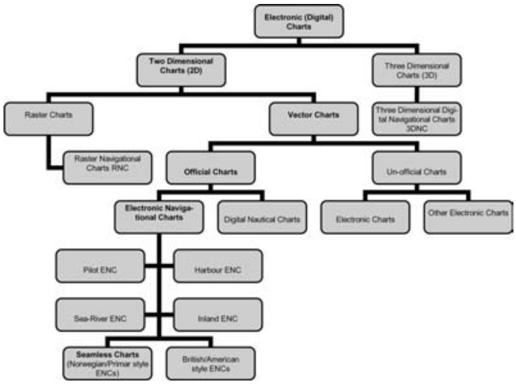


Figure 21. Electronic navigational charts general classification.

The major advantages of Marine and Inland ECDIS electronic charts are:

- provision of information for all objects in text, graphical or video format,
- detailed and concise charts presentation in all resolutions and cut-out scales,
- simple and quick update of data (digital notices to skippers),
- presentation in various detailedness (e.g. depth) adapted to the needs of the skippers,
- provision of further information beyond shore and border zones,
- adoption to the requirements of skippers, e.g. customizing the chart display brightness to the lighting conditions in the wheelhouse, dynamic objects like locking status,
- possibility of linking with the radar display, route planning and route monitoring applications, etc.

One issue that can strike is that it seems that ECS has been adopted far more successfully inland, without mandatory requirements, but because of the added value to shipping operations. This is certainly in contrast to what we have seen on SOLAS fleet.

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© 2009 Taylor & Francis Group, London, ISBN 978-0-415-80479-0

9.6 Data transmission in inland AIS system

P. Wołejsza
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: The article presents the technical aspects of applying the marine Automatic Identification System (AIS) for the purposes of vessel traffic control in inland shipping. Functional properties and requirements for inland AIS have been discussed as well as protocol alterations in relation to marine AIS, with particular consideration of messages enhancing safety of navigation and the flow capacity of inland waterways.

1 INTRODUCTION

The International Maritime Organisation (IMO) has introduced an Automatic Identification System (AIS) for the purposes of marine navigation. All sea-going vessels making international voyages and covered by Chapter V of SOLAS Convention (Safety of Life at Sea) have had to be equipped with AIS since the end of 2004.

AIS technology is also applied in the automatic recognition and control of vessel traffic in inland waterways. In particular, results reached by AIS in the scope of recognition in real time and the accessibility of worldwide standards and guidelines are helpful for safety protection in waterways.

The conformity of inland AIS with IMO SOLAS AIS permits the direct exchange of information between sea-going and inland vessels moving in mixed traffic zones.

2 PROPERTIES

AIS system applied for automatic recognition and control of inland vessel traffic has the following properties (Article 5 of Directive 2005/44/EC of the European Parliament and of the Council on Harmonized River Information Services (RIS) on Inland Waterways in the Community):

– it is an IMO-introduced marine navigation system that must be at the disposal of all vessels subject to SOLAS convention,
– it permits information transmission directly from ship to ship, ship to shore or shore to ship,
– it is a safety system fulfilling the high requirements in the range of availability, continuity and reliability,
– it permits information transmission in real time, directly between vessels,
– it is an autonomous system, without a main station, and as such does not need a central for controlling functioning,
– it was prepared based on international standards and procedures conformed to Chapter V of SOLAS convention,
– it obtained a certificate as a system enhancing safety of navigation,
– it is interoperational.

A universal inland AIS deck station, defined by IMO, ITU (International Telecommunication Union) and IEC (International Electrotechnical Commission) and recommended for inland shipping makes use of SOTDMA access method (Self-Organizing Time Division Multiple Access) in the marine VHF range (Very High Frequency). AIS receives on international VHF frequencies: AIS 1 (161.975 MHz) and AIS 2 (162.025 MHz), and can also be switched to other VHF ranges.

An inland AIS station is made up of the following elements:

– sending-receiving VHF terminal (1 transmitter/2 receivers),
– GNSS (Global Navigation Satellite System) receiver,
– processor.

Inland vessel traffic control systems must conform to marine AIS created by IMO. This means that the messages transmitted include the following data: static information, dynamic information, voyage-related information and information characteristic for inland shipping like: number of blue cones/lights according to ADN/ADNR (European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways) or the Expected Time of Arrival at lock/bridge/terminal/border (ETA).

3 FUNCTIONAL REQUIREMENTS

Inland AIS is used for transmitting information bound with vessel traffic control and safety of navigation; therefore, the messages transmitted should contain the following data (Commission Regulation (EC) No

415/2007 of 13 March 2007 concerning the Technical Specifications for Vessel Traffic Control Systems):

3.1 *Static information*

Static information given independently by a particular vessel or furnished at request:

- User identifier (MMSI – Maritime Mobile Service Identifier)
- Vessel's name
- Call sign
- IMO number * (unobtainable for inland vessels)
- Kind of ship and cargo * (altered for inland AIS)
- LOA (Length overall) (with decimetre accuracy) * (altered for inland AIS)
- Breadth overall (with decimetre accuracy)* (altered for inland AIS)
- Kind of vessel or combination (ERI – Electronic Reporting International) (for inland AIS)
- Possible cargo (for inland AIS)

Positions marked with asterisk "*" are different for inland and marine vessels and have been listed in details in the chapter **alterations in inland AIS protocol**.

3.2 *Dynamic information*

Dynamic information on the ship has, in so far as possible, the same parameters and the same structure in the case of inland and sea-going vessels. Unused parameters should be marked as "inaccessible":

- Location (WGS 84)
- SMG (speed made good)*(qualitative information)*
- CMG (course made good) (qualitative information)*
- True course (qualitative information)*
- Speed of course alteration
- Accuracy of location (GNSS/DGNSS)
- Time of device for electronic determination of location
- Navigational status
- Set of blue marks (for inland AIS)*
- Quality of information on speed (for inland AIS /from deck sensor or GNSS)
- Quality of information on course (for inland AIS /from deck sensor or GNSS)
- Quality of information on true course (for inland AIS /from certified sensor (e.g. gyro) or non-certified sensor)

3.3 *Information on the voyage*

Information on the voyage is given independently by a particular vessel or furnished at request:

- Port of destination (ERI location code)
- Dangerous cargo category
- Expected Time of Arrival
- Maximum current static draft * (altered for inland AIS)
- Classification of dangerous cargo (for inland AIS)

3.4 *Information on traffic management*

Information on traffic management concerns exclusively inland shipping and is transmitted as need arises or at request, to or from inland vessels:

- Identifier of lock/bridge/terminal (UN/LOCODE – United Nations Location Code) (for inland AIS)
- Expected Time of Arrival at lock/bridge/terminal (for inland AIS)
- Number of tugs (for inland AIS)
- Vessel's air draft (for inland AIS)

3.5 *Information on the number of persons aboard*

It is recommended that information on the number of persons aboard should be passed on demand in the case of the event happening in the form of addressed messages from ship to shore:

- Total number of persons
- Number of crew members (for inland AIS)
- Number of passengers (for inland AIS)
- Number of deck personnel (for inland AIS)

3.6 *Information on signal status*

Information on signal status is transmitted in the form of shore to ship message:

- Signal location (WGS84) (for inland AIS)
- Signal forma (for inland AIS)
- Light signal status (for inland AIS)

3.7 *EMMA (European Multiservice Meteorological Awareness) warnings*

EMMA warnings, information on water level and safety messages are transmitted in the form of shore to ship messages, in the form of addressed or sent messages:

- Location (WGS 84) Local weather warnings (for inland AIS)
- Local information on water levels (for inland AIS)

4 ALTERATION IN INLAND AIS PROTOCOL

As platform for inland AIS, inland versions of portable class A stations are recommended or class B "SO" stations with the application of SOTDMA techniques. Class B "CS" stations using CSTDMA (Carrier Sense Time Division Multiple Access) techniques, on the other hand, cannot be used, as they do not secure the same effects as class A or "SO" B equipment. "CS" devices do not ensure successful data transmission by radio, nor do they make possible the transmission of messages on the presented technical specifications required for inland AIS. As long as class B "SO" devices are inaccessible, class A versions are applied adapted to the needs of inland shipping, in accordance with IMO SOLAS regulation (IMO

Table 1. FI for inland AIS (Commission Regulation (EC) No 415/2007 of 13 March 2007 concerning the Technical Specifications for Vessel Traffic Control Systems).

FI	Area	Message name	Sender	Message sent	Message addressed	Description
10	Gen	Static data on vessel and voyage	Ship	X		See: Message FI10: Static data on vessel and voyage
21	VTS	VTS Expected Time of Arrival at lock/ bridge/terminal	Ship		X	See: Message FI21: Expected Time of Arrival at lock/bridge/terminal
22	VTS	RTA – Requested Time of Arrival at lock/bridge/terminal	Shore		X	See: Message FI22: RTA – Requested Time of Arrival at lock/bridge/terminal
23	VTS	EMMA weather warning	Shore	X		See: Message FI23:EMMA weather warning
24	VTS	Water levels	Shore	X		See: Message 24: Water levels
40	A-to-N	Signal status	Shore	X		See: Message 40: Signal status
55	SAR	Signal status	Ship	X	X (best)	See: Message FI55: Number of persons on deck

MSC.74(69) Annex 3 “Recommendations on Performance Standards for a Universal Shipborne Automatic Identification System (AIS)” IMO (International Maritime Organisation) 1998).

Function Identifiers (FI) for inland AIS are assigned and applied in accordance with recommendations ITU-R M.1371-1 Table 37B (Recommendation ITU-R M.1371-1 – “Technical Characteristics for a Universal Shipborne Automatic Identification System Using Time Division Multiple Access in the VHF Maritime Mobile Band”. ITU (International Telecommunication Union) 2001).

Each FI within the framework of inland AIS is to be assigned to one of the following groups of application areas:

– for general use (Gen),
– vessel traffic control system (VTS – Vessel Traffic System),
– navigation support (A-to-N – Aid to Navigation),
– search and rescue (SAR – Search And Rescue).

4.1 *Message FI 10*

Static data on vessel and voyage are presented in table 2 (only inland vessels make use of this message).

4.2 *Message FI 21: Expected Time of Arrival at lock/bridge/terminal (ETA).*

Within 15 minutes from sending the message, message no. 22 should arrive, confirming reception. If there is no such message, message no. 21 should be repeated.

4.3 *Message FI 22: Requested Time of Arrival at lock/bridge/terminal (RTA).*

Messages about RTA for a given ship are transmitted exclusively by base stations in answer to message no. 21.

Table 2. Message FI 10 (Commission Regulation (EC) No 415/2007 of 13 March 2007 concerning the Technical Specifications for Vessel Traffic Control Systems).

Parameter	Description
Unique European vessel identification number	8 signs in 6-bit ASCII code
Kind of vessel or combination	ERI classification number: 1 Type of ship and convoy, acc. to ANNEX E: Types of ships acc. to ERI
Dangerous cargo	Number of blue cones /lights 0–3; 4 = flag B, 5 = default value = unknown
Possible cargo	1 = loaded, 2 = unloaded, 0 = inaccessible/default value, 3 not applied
Quality of speed data	1 = high, 0 = low/GNSS = default value
Quality of course data	1 = high, 0 = low/GNSS = default value
Quality of true course data	1 = high, 0 = low = default value

4.4 *Message FI 55*

Information of number of persons aboard are presented in table 5.

4.5 *Message FI 23: EMMA weather warning*

EMMA weather warning is sent to vessel using graphic symbols on ECDIS screen (Electronic Chart Display and Information System). This message serves the purpose of sending EMMA data by means of AIS channel. This message is directed to all vessels in a given zone and is transmitted exclusively by base stations.

Table 3. Message FI 21 (Commission Regulation (EC) No 415/2007 of 13 March 2007 concerning the Technical Specifications for Vessel Traffic Control Systems)

Parameter	Description
UN country code	2 signs
UN location code	3 signs
Fairway section number	5 signs
Terminal code	5 signs
Fairway hectometre	5 signs
Expected Time of Arrival at lock/ bridge/terminal	Expected Time of Arrival: MMDDGGMM UTC
Number of tugs	0–6, 7 = unknown = default value
Vessel's air draft	0–4 000 with accuracy to 1/100 m

Table 4. Message FI 22 (Commission Regulation (EC) No 415/2007 of 13 March 2007 concerning the Technical Specifications for Vessel Traffic Control Systems)

Parameter	Description
UN country code	2 signs
UN location code	3 signs
Fairway section number	5 signs
Terminal code	5 signs
UN country code	5 signs
Requested Time of Arrival at lock/ bridge/terminal	Requested Time of Arrival: MMDDGGMM UTC
Status of lock/bridge/terminal	0 = active 1 = partly restricted service (difficult technical conditions, only one chamber available etc.) 2 = inactive, 3 = unavailable

Table 5. Message FI 55 (Commission Regulation (EC) No 415/2007 of 13 March 2007 concerning the Technical Specifications for Vessel Traffic Control Systems)

Parameter	Description
Number of crew members aboard	0–254 crew members, 255 = unknown = default value
Number of passengers aboard	0–8 190 passengers, 8 191 = unknown = default value
Number of deck personnel aboard	0–254 deck personnel, 255 = unknown = default value

4.6 *Message FI 24: Water levels*

This message serves the purpose of informing masters about the current water level in the zone they are in. It is short-term additional information about water levels given by means of messages for masters. The competent authority establishes the frequency of updating. Data coming from more than 4 measuring instruments can be transmitted by means of multiple messages, which are directed to all vessels in a given zone and are sent exclusively by base stations in regular time intervals.

4.7 *Message FI 40: Signal status*

This message, directed to all vessels in a given zone, is sent exclusively by base stations. Information on light signalling is displayed as dynamic symbols on an external ECDIS display. This message is sent in regular time intervals.

5 RECAPITULATION

The main task of a VTS system is managing vessel traffic in a designated area, including support of navigation, traffic organisation, optimising the waterway flow capacity, planning the functioning and servicing of bridges or locks. AIS system in the inland version will ensure effective information exchange between all participants of inland transport, thereby accelerating the transport process and increasing its safety.

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Chapter 10. Route planning and weather navigation

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10.1
Multi-objective optimization of motor vessel route

S. Marie & E. Courteille
Department of Mechanical Engineering and Automation, Institut National des Sciences Appliquées, Rennes, France

ABSTRACT: This paper presents an original method that allows computation of the optimal route of a motor vessel by minimizing its fuel consumption. The proposed method is based on a new and efficient meshing procedure that is used to define a set of possible routes. A consumption prediction tool has been developed in order to estimate the fuel consumption along a given trajectory. The consumption model involves the effects of the meteorological conditions, the shape of the hull and the power train characteristics. Pareto-optimization with a Multi-Objective Genetic Algorithm (MOGA) is taken as a framework for the definition and the solution of the multi-objective optimization problem addressed. The final goal of this study is to provide a decision helping tool giving the route that minimizes the fuel consumption in a limited or optimum time.

1 INTRODUCTION

Ship weather routing develops an optimum track for ocean voyages based on forecasts of weather, sea conditions, and ship's characteristics. Within specified limits of weather and sea conditions, the term optimum is used to mean maximum safety and crew comfort, minimum fuel and oil consumption, minimum time or distance underway, or any desired combination of these factors.

There exists many works dealing with the problem of optimal ship weather routing, in which motor or sailing vessels are considered. The approaches in the literature may be divided into four categories: isochrone construction, application of the calculus of variation, dynamic programming and evolutionary algorithms.

James (1957) proposed a scheme for non-variable weather conditions using lines of equal-time, or isochrones to achieve minimal-time objective. This method is very efficient for solving the problem of determinist minimal-time weather routing but is not adapted for minimization of the vessel's fuel consumption. Numerous variation of this type of method have been presented. For example Hagiwara & Spaans (1987) presented an improvement of isochrone definition for sail-assisted motor vessel routing. In addition to time objective, the author tried to minimize fuel consumption but the method is not very efficient because the propeller speed is kept constant on the track.

Haltiner, Hamilton and Árnason (1962) solved the same problem by using the calculus of variations. This method is based on parametric curves obtained by solving the associated Euler differential equation by relaxation methods. Bleick & Faulkner (1965) extended this approach to the case of deterministic variations of sea state. This definition is mathematically elegant but impractical for ship weather routing because of convergence problems.

The third approach was proposed by Zappoli (1972), who treated the minimal time problem as a decision process solvable using dynamic programming. The sailing domain is discretized using grid refinement techniques. Allsopp & al. (2000), modified this method integrating branching scenario structure to model the manner the weather will evolve in time. The main advantage of that kind of method is that the problem is divided into a set of linked stages and the optimal decision depends on decisions made in the previous stages. But, for fine grid, the calculation time may be very high and the amount of data very large.

The most recent approaches use B-spline technics and evolutionary algorithms in order to minimize fuel consumption and maximize safety. Harries, Heimann and Hinnenthal (2003) proposed such a method for large motor vessels using Multi-Objective Genetic Algorithms. Hinnethal and Saertra (2005) improved this method considering the stochastic nature of weather along the route. Böttner (2007) recently used this work combined with dynamic programming for costal approach in order to propose the best possible track from harbor to harbor. These methods are characterized by a low number of free variables to describe both the course and the speed of the boat. Moreover, a high number of route variants can be considered from which Pareto optimal solutions may be identified.

In the four different approaches, the scheme for optimisation is almost the same:

- Mathematical modeling of the ship to compute the objectives,
- 3-D interpolation (time and space) of weather and sea state data,

– Parametric route definition,
– Optimization of the route using an algorithm.

Our work is based on a new discretization of the research space based on few physical parameters. This parametric definition of the griding makes it understandable and easy to tune. Moreover this kind of meshing may be applicable for all type of vessels, journeys and all weather conditions are easily taken into account. The gridding of the sail area is systematic and uniform since it is based on spherical geometry and accepts constrains like bathymetric data. Our work is related to the method proposed by Harries & al. because we kept their definition of both the geography and speed since it allows the complete location of the boat in space and time. The modeling of motor vessels is not the purpose of this work and will just be briefly presented. Future works concern the identification of the vessel model using fuzzy logic technique in order to obtain an accurate consumption model. Since this identification is not achieved yet, a model from the literature will be used to present this new gridding method.

The meshing of the explored area is presented first. Then, the way of constructing routes is shown and a sensitivity of the meshing is presented. Next, the way of modeling a motor vessel is introduced. Finally, results of numerical optimizations are presented in order to evaluate the limitations and benefits of the proposed meshing method.

2 MESHING OF THE EXPLORED AREA

The new automatic meshing method that we propose is based on spherical rhombus where two of the opposite vertexes are the departure and the arrival points. The main advantages of this discretization of the sailing area are:

– The genericity of its construction taking into account the sea-beds geography, the time dependant meteorological data and the characteristics of the vessel.
– The systematic gridding of the explored area with few physical parameters.
– The automation of its calculation leading to optimizable routes.
– The possible reactualization of the rhombus to change the routing policy during the sailing.

2.1 *Rhombus definition*

In this part M denotes the departure point, M' the arrival one and O is the center of Earth considered spherical. (P_1) is the plane containing the lines (OM) and (OM') carrying respectively vectors **i** and **j**. γ is the angle between these two vectors and **k** is their bisectrix. **w** is one vector normal both to **i** and **j**. We also define the two related unit vectors $\mathbf{k}_u$ and $\mathbf{w}_u$. Let be (P_2) the plane containing **k**, **w**, the two remain vertexes of the rhombus A and B and point O. The lines (OA) and (OB) are directed by vectors **a** and **b**. We defined $(\mathbf{a}, \mathbf{b}) = 2\delta$. This notation is recalled in the figure 1.

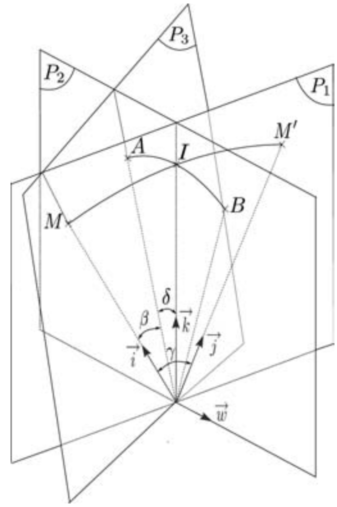


Figure 1. Main planes to define the meshing.

Point I denotes the intersection between the great circles $\widehat{MM'}$ and $\widehat{AB}$. (P_3) is the plane containing **i** and **a**, we have $(\mathbf{i}, \mathbf{a}) = \beta$. This angle is the image of the orthodromic distance between M and A. Knowing the maximal speed of the vessel V_{Max}, imposed by the design of the hull and the power train characteristics, and the desired time of sailing T_{obj}, the maximal distance that can cross the vessel during the time window is:

$$D_{Max} = T_{Obj} V_{Max}$$

By this mean we can set the maximal distance on the great circle route MA:

$$MA = \frac{rD_{Max}}{2}, \tag{1}$$

where r is an dimensionless factor lower than the unit used to get some margin. From this equation (1), angle β is calculable as follow:

$$\beta = \frac{rT_{Obj} V_{Max}}{2R}, \tag{2}$$

with R the Earth mean radius. To compute the value of δ angle, the following vectorial equations are used:

$$a = cos\delta k_u - sin\delta w_u, \tag{3}$$

$$b = cos\delta k_u + sin\delta w_u, \tag{4}$$

$$i.a = i.(cos\delta k_u - sin\delta w_u). \tag{5}$$

Developing this relation (5), one can write:

$$\delta = \cos^{-1}\left(\frac{\cos\beta}{\cos\left(\frac{\gamma}{2}\right)}\right), \tag{6}$$

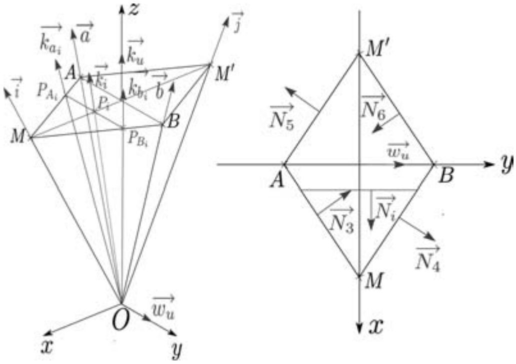


Figure 2. Definition of planes.

$$\begin{cases} \lambda = \tan^{-1}\left(-\frac{y}{x}\right) \\ \phi = \sin^{-1}\left(\frac{z}{R}\right) \end{cases}. \tag{7}$$

Using the inverse spherical transformation (7) and the definition of **a** and **b** vectors (3,4), it is possible to compute the spherical coordinates of A and B:

$$\lambda_A = \tan^{-1}\left(-\frac{\cos\delta \frac{k_{uy}}{\|\vec{k_u}\|} - \sin\delta \frac{w_{uy}}{\|\vec{w_u}\|}}{\cos\delta \frac{k_{ux}}{\|\vec{k_u}\|} - \sin\delta \frac{w_{ux}}{\|\vec{w_u}\|}}\right), \tag{8}$$

$$\phi_A = \sin^{-1}\left(\cos\delta \frac{k_{uz}}{\|\vec{k_u}\|} - \sin\delta \frac{w_{uz}}{\|\vec{w_u}\|}\right). \tag{9}$$

Where λ_I is the longitude of point I and ϕ_I denotes its latitude. The same kind of relations can also be written for point B.

2.2 *Meshing's levels calculation*

The previous construction is extended in order to define the N_l levels of the meshing. For that purpose, i planes P_i are defined, $i \in [1, N_l - 2]$. These planes contain the vectors **w** and $\mathbf{k}_i$ (Fig. 2). The components of vector $\mathbf{k}_i$ are calculated according to:

$$\begin{cases} \mathbf{i}.\mathbf{k}_i = \cos\left(i \frac{\gamma}{N_{Lon} - 1}\right) \\ \mathbf{i}.\mathbf{k}_i = 0 \\ \mathbf{k}_i.\mathbf{j} = \cos\left(\gamma - i \frac{\gamma}{N_{Lon} - 1}\right) \end{cases}. \tag{10}$$

By solving the system (10) the components of $\mathbf{k}_i$ are computed. To complete the spherical pyramid (Fig. 2), three more plans comparable to (P_3) are defined: (P_4) contains **i** and **b**, (P_5) contains **j** and **a**, (P_6) contains **j** and **b**.

For each of the above mention planes, their normal $\mathbf{N}_3$, $\mathbf{N}_4$, $\mathbf{N}_5$, $\mathbf{N}_6$ are defined, $\mathbf{N}_i$ the normal to (P_i) is also calculated. The intersections between (P_i), (P_n) and (P_{n+1}) $(n = \{3, 5\})$ are the two lines called (OP_{A_i}) and (OP_{B_i}) oriented respectively by vectors $\mathbf{k}_{a_i}$ and $\mathbf{k}_{b_i}$. The components of these vectors are calculated according to:

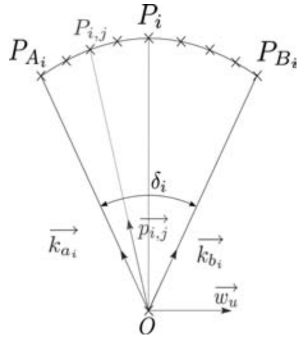


Figure 3. Vectors and nodes in plane P_i.

– If $(\mathbf{i}, \mathbf{k}_i) \le \frac{\gamma}{2}$,
then $\begin{cases} \mathbf{k}_{a_i} = \mathbf{N}_i \wedge \mathbf{N}_3 \\ \mathbf{k}_{b_i} = \mathbf{N}_i \wedge \mathbf{N}_4 \end{cases}$

– If $(\mathbf{i}, \mathbf{k}_i) > \frac{\gamma}{2}$,
then $\begin{cases} \mathbf{k}_{a_i} = \mathbf{N}_5 \wedge \mathbf{N}_i \\ \mathbf{k}_{b_i} = \mathbf{N}_6 \wedge \mathbf{N}_i \end{cases}.$

The related unit vectors $\mathbf{k}_{a_i u}$ and $\mathbf{k}_{b_i u}$ are defined. In each level of the meshing *i.e.* plane P_i (Fig. 3), nodes of the level are defined. The distance between 2 nodes is constant and defined by the parameter D_L. As a result, in a level, N_{δ_i} nodes $P_{i,j}$ are defined with:

$$N_{\delta_i} = int\left(\frac{R\delta_i}{D_L}\right) + 1. \tag{11}$$

The angle δ_i between vectors $\mathbf{k}_{a_i}$ and $\mathbf{k}_{b_i}$ is defined by:

$$\delta_i = \cos^{-1}(\mathbf{k}_{a_i u}.\mathbf{k}_{b_i u}). \tag{12}$$

For each node in the level, directing vector $\mathbf{P}_{i,j}$ of the line $(OP_{i,j})$ is defined by the following system:

$$\begin{cases} (\mathbf{p}_{A_i u}, \mathbf{p}_{i,j}) = \cos\left(j \frac{\delta_i}{N_{\delta_i}}\right) \\ (\mathbf{p}_{i,j}, \mathbf{p}_{B_i u}) = \cos\left(\delta_i - j \frac{\delta_i}{N_{\delta_i}}\right) \\ (\mathbf{p}_{i,j}, \mathbf{N}_i) = 0 \end{cases}. \tag{13}$$

So the cartesian coordinates of the jth node of the ith level are:

$$\begin{cases} \mathbf{OP}_{i,j} = R\mathbf{p}_j \\ i \in [1, N_l - 2] \\ j \in [1, N_{\delta_i}] \end{cases}. \tag{14}$$

Using the inverse spherical transformation (7), the coordinates of $P_{i,j}$ (14) are expressed within the spherical coordinate system.

2.3 *Limitation of the possible nodes*

From vectorial cartographies, the matrix giving the depth of water according to longitude and latitude of meshing's points is compared with the draught of the boat. The nodes at which the depth is insufficient are removed from the grid (14).

A criterion of maximum course between two successive nodes is also defined. This criterion makes it possible to exclude the nodes which move the ship too away from its final destination M'.

3 ROUTE DEFINITION

3.1 *Geographical definition of routes*

3.1.1 *Definition of routes*

Each possible route is defined using a navigable node of each level of the meshing. The nodes $(M, P_1, \ldots P_{N_l-2}, M')$ define the control points of the associated Bézier curve. We choose Bézier curve since it begins at M and end at M' in addition the curve is always in the convex hull of the control polygon. For recall the Bézier curve is defined by:

$$\sum_{i=0}^{(N_l-1)} \mathcal{B}_i^{(N_l-1)}(t) P_i, \quad t \in [0,1]. \tag{15}$$

Where $\mathcal{B}_i^{(N_l-1)}(t)$ stand for the Bernstein basis polynomials.

3.1.2 *Discretization of Bézier curve*

Moreover because of its parametric definition the Bézier curve is discreditable. This discretization is done relatively to a parameter N_{CC} corresponding to the maximal number of course changes per hour. The number of segments of a route N_C is defined from the minimal distance *i.e.* the orthodromic distance $\widehat{MM'}$ sailed at the maximum speed of the vessel V_{Max}:

$$N_C = N_{CC} \frac{d_{MM'ortho}}{V_{Max}}. \tag{16}$$

As a result, the points P_k defining the route are computed as presented below:

$$\left\{P_k \in \mathbb{R}^2 \left| \sum_{i=0}^{(N_l-1)} \mathcal{B}_i^{(N_l-1)}(t) P_i, \quad t = \frac{k}{N_c}, \quad k = \{0, \ldots, N_C\}\right.\right\}. \tag{17}$$

The discretization of Bézier curves is done because on each facet of the route, we consider that both the weather and sea state remain constant. It also allows to define loxodromic courses between P_k and P_{k+1} which leads to a route defined by waypoints and courses. N_{CC} must be set with great care because it corresponds to a compromise between the number of course changes that the captain has to perform and the approximation of the weather field along the course.

3.2 *Velocity along a route*

In order to locate the vessel both in time and space, the velocity on the course is set. As a result along each facet of the route, the time dependant weather data are known. Moreover the crossing time $T_{P_k P_{k+1}}$ is easily calculable.

The target speeds of the vessel V_T are included between two boundaries: $V_{T_{Max}}$ and $V_{T_{Min}}$. $V_{T_{Min}}$ has to be tuned by the captain. The number of target speeds is N_{TS}. Each target speed is valid on several segments of the discretized route. The number of facets N_S on which V_T is valid is defined by:

$$N_S = int\left(\frac{N_C}{N_{TS}}\right) + 1. \tag{18}$$

Table 1. Parameters of weather and sea state.

V_r	True wind speed	$m.s^{-1}$
ϕ_r	True wind direction	$\circ$
V_c	Current speed	$m.s^{-1}$
ϕ_c	Current direction	$\circ$
H_w	Swell height	m
T_w	Swell period	s
ϕ_w	Swell direction	$\circ$

3.3 *Meteorological conditions along the route*

The weather and the sea state at the current position of the vessel are extracted from GRIB files defined with a regular $1.25^\circ \times 1^\circ$ grid downloaded from NOAA ftp[1]. These files gathered the meteorological data for a 180 hours time window with a 3 hours step.

The decoding of these files allows the construction of true wind, current and waves fields for the sailing time window. The parameters of these fields are presented in Table 1.

As the meteorological grid weather does not correspond to the route's points P_k, a space interpolation of the data is done. For that purpose, we used 2D linear interpolation techniques to estimate the encountered conditions during the whole time window for each P_k. In addition, the time dependency of the fields can be easily taken into account by interpolation in time.

4 MESHING SENSITIVITY TO ITS PARAMETERS

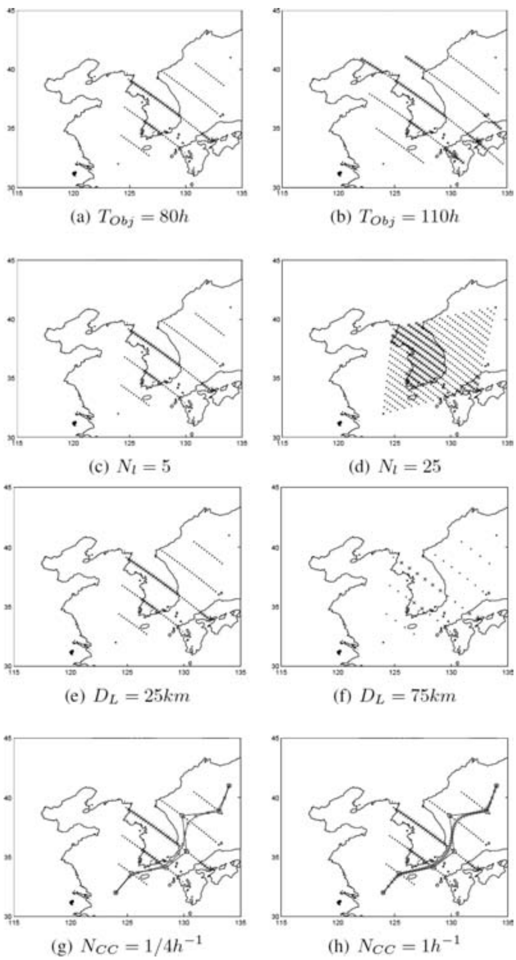
The main advantage of the method compared to the previous approaches is that the rhombus definition is based on physical parameters (Tab. 2) easily adjusted and tuned by the captain. The journey is defined by $\mathbf{P}_{Dep}$ and $\mathbf{P}_{Arr}$. The design of the boat imposes V_{max} and the four other meshing's parameters define its geometry. On Fig. 4, two different values of each adjustable parameters are shown. The dots corresponds to the navigable nodes and the cross to the non navigable ones These parameters are left in user's hand but a great attention must be brought to their value since they define the manner the research space is discretized and then the fineness of the solution.

Moreover the discretization of the research space is uniform because of the spherical definition of the

[1] *ftp://polar.ncep.noaa.gov/pub/waves/latest_run/*

Table 2. Physical parameters defining the meshing.

$\mathbf{P}_{Dep}$	Departure point	°,°
$\mathbf{P}_{Arr}$	Arrival point	°,°
V_{max}	Maximum speed of the vessel	$km.h^{-1}$
T_{obj}	Objective time	h
N_l	Number of levels	–
D_L	Distance between nodes	km
N_{CC}	Course changes per hour	h^{-1}



(a) $T_{Obj} = 80h$ (b) $T_{Obj} = 110h$ (c) $N_l = 5$ (d) $N_l = 25$ (e) $D_L = 25km$ (f) $D_L = 75km$ (g) $N_{CC} = 1/4h^{-1}$ (h) $N_{CC} = 1h^{-1}$

Figure 4. Sensitivity to meshing's parameters.

meshing. This property is interesting for long voyages since the routes will be equi-distributed on Earth's surface. Of course for short travels, the Earth's roundness is too small to have an influence on the meshing definition so a planar definition of the rhombus is more convenient.

5 CONSUMPTION MODELING

At this point, the set of possible routes has been defined and the physical magnitudes have been calculated. In the perspective of optimizing the route of the vessel, a cost function has to be defined in order to select the best track.

In the literature, various approaches are proposed. For example Zappoli (1972) chose the sailing time as cost function, Hinnenthal & al. (2003) chose both the consumption and the estimate time of arrival. But to compute these functions, the ship performances in a seaway must be accurately known Journée & Mejiers (1980). Most of the works use parametric models in order to estimate the boat's behavior. The scheme of calculation in the recent approaches is often the same one:

- Estimation of the resistances acting on the hull:
  - Still water resistance based on regression analysis of model tests and full-scale data (Haltrop, Van Oomertsen, …),
  - Wind resistance of the emmerged part of the vessel (Isherwood),
  - Added resitance due to waves (Gerristma, Boese, . . .),
- Operating point of the propeller with the ITTC power prediction method,
- Operating point of the main engine to estimate the consumption.

These parametric models are well known and controlled but their identification requires specific equipments such has wind tunnels or towing tanks, realization of instrumental models, instrumentation of the ship for full-scale measurements. The calculation time may be rather important and the measurement cost very high to get an efficient estimator of performances so applications of these methods are limited. Moreover the parameters are time dependent if we take into account the fouling of the hull leading to an increase of resistances for example. In addition, these models are not generic, the calculation method must be adapted to each hull's shape.

To analyze the efficiency of the proposed meshing method, we introduce a parametric model that will react to the encounter sea conditions. We are aware that such a raw model could not describe finely the resistances that encounter a boat in a real seaway but it as to be implanted to test the general approach we propose. The consumption model will further be identified on board using fuzzy logic technics. As the meshing method is uncoupled from the modeling, any function cost can be used to estimate the efficiency of a particular route. We used the ship presented in Hagiwara (1987) since many information are available and the time calculation cost is low (3 *ms*). For our routing scheme, we chose the consumption and the sailing time as estimators of the vessel efficiency.

5.1 *Scheme of calculation*

The scheme of consumption calculation is presented on the figure 5. As presented earlier, both the

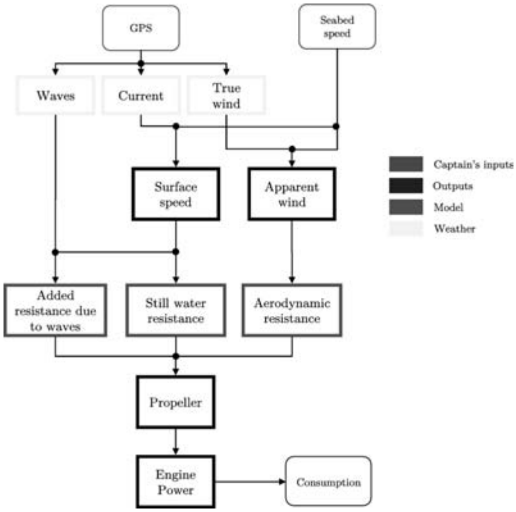


Figure 5. Scheme calculation of the consumption.

geography and the velocity are defined for a route, as a result, the inputs of the consumption calculation are the GPS position of the boat and the desired seabed velocities V_T.

Classically, the composition between true wind and seabed velocity of the vessel leads to the apparent wind. In order to get the desired seabed velocity, the current effects must be compensated if the resulting relative speed does not exceed the limitation due to the vessel design *i.e.* the maximal speed of the vessel V_{max}. The drifting of the vessel is neglected here.

5.2 *Resistances computation*

In this part the relations used to compute the resistances acting on the hull are presented rapidly. They will allow to estimate the power that has to be delivered by the vessel's engine.

- **Still water resistance** R_{SW} is the first resistance acting on the vessel. It corresponds to the energy used to overcome the frictional resistance of the hull plus the one used to create the bow wave.
- **Aerodynamic resistance** R_A is the action of the wind onto the emerged part of the vessel.
- **Added resistance due to waves** R_{AW} is the increase of resistance due to the encountered waves. It depends of their average period, significative height and mean direction.

The total resistance R_T is the global resistance acting on the hull. Its value is calculated according to:

$$R_T = R_{SW} + R_A + R_{AW}. \tag{19}$$

The numerical values of the model parameters and the vessel design, are presented in Hagiwara & Spaans (1987).

5.3 *Propulsion characteristics*

As the resistances acting on the hull are known, the propulsion system has to be modeled in order to evaluate the torque and power that must be delivered by the engine at the target velocity V_T. For the routing example we chose a 8 *m* diameter fixed pitch Wageningen B5-75 screw series propeller, Carlton (2007) and a 10000 *kW* Wärtsilä engine (2007).

Propeller thrust, torque, rate of revolution The propeller thrust T_P, torque Q_P and power P_P are calculated using the ITTC scheme of calculation (1978). Their calculation are well known and will not be discussed here. The propeller's rate of revolution is adjusted to obtain the proper thrust T_P.

Engine power and consumption For a known propeller and engine, a fixed propeller revolution rate and a given ship speed, the engine power can be calculated as follows:

$$P_e = \frac{R_T V_f}{\eta_H \eta_0 \eta_r \eta_m}, \tag{20}$$

with $\eta_H = \frac{1-t}{1-w}$ the efficiency of the hull and t the thrust deduction fraction due to suction of the water in front of the propeller, w the wake fraction, η_0 the open water efficiency, η_r the relative rotative efficiency and η_m the mechanical efficiency of shaft bearing.

The consumption of the engine is calculated knowing the delivered power. For that purpose, we use the specific consumption law C_s given by the engine manufacturer. For a given rate of revolution N_e and power P_e of the engine, the hourly consumption is given by:

$$C = P_e C_s(N_e). \tag{21}$$

The unit of P_e is $L.h^{-1}$.

6 OPTIMIZATION SCHEME

6.1 *Search method*

6.1.1 *Performances indices*

The goal of the optimization is to minimize the antagonist objectives: the consumption C and the sailing time T. A numerical optimization of a route off Corea is presented hereafter (Fig. 6). The journey is defined between $\mathbf{P}_{Dep} = (133°40°)$ and $\mathbf{P}_{Arr} = (122.5°\ 32.5°)$. The number of level is $N_l = 7$, the distance between nodes of a level is $D_L = 25\,km$ and the number of course changes per hour is $N_{CC} = 1\,h^{-1}$. The number of target speeds is $N_{TS} = 8$. For this application we used the meteorological data of the 23rd April 2008 at 0:00 GMT which will be the departure time.

6.1.2 *Pareto-optimal solutions*

Solving this optimization problem with conflicting objectives across a high-dimensional research space is a difficult goal. Instead of a single optimum, there is rather a set of alternative trade-offs, generally known as Pareto-optimal solutions. Various evolutionary approaches to multi-objective optimization have

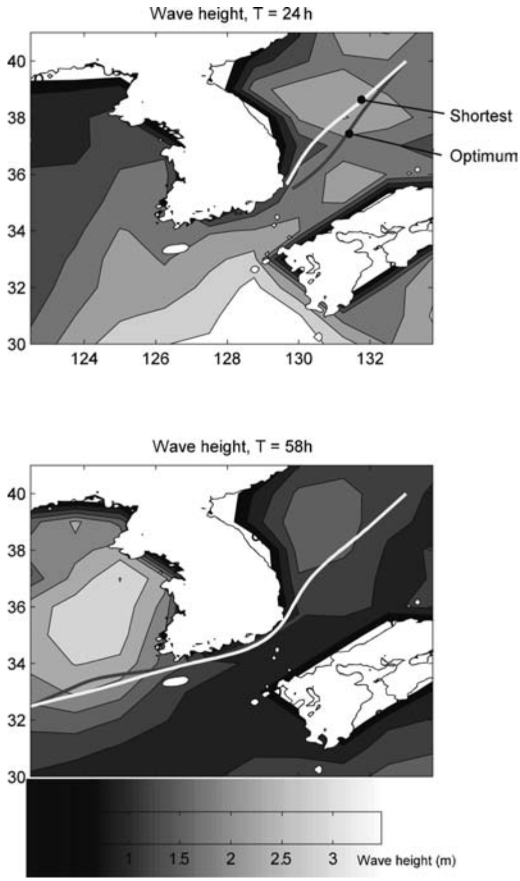


Figure 6. Comparison between shortest and optimal routes in wave field.

been proposed since 1985, capable of searching for multiple Pareto-optimal solutions concurrently in a single simulation run, Valdhuizen & Lamont (2000). The optimization program FRONTIER®[2] and the technical computing software MATLAB® are used to set up the framework of the multi-objective design optimization study of weather routing. The Multi-objective Genetic Algorithm (MOGA), implemented first by Fonseca & Fleming (1998), is used to perform the optimization problem.

6.1.3 *Design parameters*

The number of parameters necessary to define a route is $(N_l - 2 + N_{TS})$. For each level of the meshing the associate parameter is the index j of the node $P_{i,j}$. Concerning the target speeds, the parameters are within the boundary previously presented and their step is 0.1 *kn*.

6.1.4 *Global optimization process*

The algorithm will attempt a number of evaluations equal to the size of the initial population for the MOGA multiplied by the number of generation. The initial population is generated by a random sequence of 60 designs. The major disadvantage of the MOGA is mainly related to the number of evaluations necessary to obtain satisfactory solutions. The search for the optimal solutions extends in all the directions from design space and produces a rich data base and there is not a true stop criterion. The numerical evaluation of the performances calls upon MATLAB codes is not so expensive in terms of computing time (about 2 *s*). In an attempt to solve the optimization problem in an acceptable timeframe, the number of generations evaluated is almost 70, i.e. 4000 designs in all. The required computation time for the global optimization process is about 2 hours (2.4 GHz / 3.0 Gb RAM). Integrating a Response Surface Methodology to reduce the computation time could be an interesting extension of our work especially if one wants to achieve on board routing.

[2] http://www.esteco.com/

Table 3. Comparison of the optimum route to the shortest one.

Route	Distance (*km*)	Time (*h*)	Fuel (*t*)
Shortest	1337.7	56.8	198.4
Optimal	1342.1	56.8	188.4

6.2 *Numerical optimizations*

The time dependency of the sea state and wind field is taken into account with linear interpolation in time. Figure 6 presents an example of weather routing. On these maps, two positions of the vessel are shown. For the analysis of the optimization, we compute the shortest path and we tune the constant velocity on this path so that the sailing time is the same as the optimal one. The comparison between these two routes is done in Table 3.

This example puts forward the interest of the routing weather for motor vessel. We have shown that a longer distance of journey does not imply automatically an increase of consumption. The example above shows that a saving of 5% is realizable on the chosen journey. The economy are not very large because the distance to be traversed is too short. Moreover, the sea is not rough, the maximum height of waves during the journey is only 2 *m*. Another problem that might occur is the spatial interpolation of the conditions. In the NOAA's GRIB, on earth, the fields are not known so an arbitrary value is set (for instance 0). This unknowing of the fields leads to inconsistent value of the advancing resistance along the coast that might distorted the results.

7 CONCLUSION & FUTURE WORK

This paper presents a brief outlook to motor vessel routing using deterministic weather forecasts. A method for spatial and temporal generation of route variants based on a generic and automatic meshing method has been presented. The major advantage of this technic is the physic based definition of the rhombus and the low number of free variables used to define a route. The ship route was optimized using multi-objective algorithm for a deterministic weather case. The reasonable computation time will allow the use of this method for on board routing applications. Pareto-optimization may be considered as a tool providing a set of efficient solutions among different and conflicting objectives, under different constraints. The final choice remains always subjective and is let to the user's hands.

Future works concern the improvement of the consumption prediction model using on board measurements and fuzzy logic identification technics. We will also investigate the routing of wail-assisted motor vessels. The use of these technics will allow the quick establishment of reliable models of different types of vessels keeping the measurement cost very low since no tawing tank, wind-tunnel tests or models will be necessary. An other aspect that has not been discussed in this paper is the stochastic nature of weather and sea conditions that must been taken into account. This aspect will also be investigated using robust optimization technics. The reactualization of the routing policy during the journey will also be considered for long travels. Thus we will be able to integrate the most recent weather data.

ACKNOWLEDGEMENTS

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

10.2 Application of the 1-2-3 rule for calculations of a vessel's route using evolutionary algorithms

B. Wiśniewski, P. Medyna & J. Chomski
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: An example is shown of the 1-2-3 rule application for calculations to determine a route avoiding tropical cyclones. The dynamic programming used is based on regularly received weather reports containing present and forecast data on tropical cyclones. The results were compared with the *post factum* calculated route which utilized only weather analyses concerning the relevant moments of the voyage and with routes calculated using the cyclone fuzzy domain as an area dangerous to navigation. The calculations were made in the evolutionary algorithms environment.

1 INTRODUCTION

1.1 *The 1-2-3 Rule*

The 1-2-3 rule consists in extending the forecast storm field of the cyclone with an approximated value of the forecast error based on 10 years of the relevant forecast time interval. The rule is recommended for the North Atlantic waters, but it can be easily adopted for other sea areas. The mean error of a given forecast is added to the largest forecast radius of the stormy area. Consistently, 100 Nm distance is added as the forecast error to the longest radius of the stormy area for 24 hour forecast for all quadrants. Similarly, 200 Nm is added for 48 hour forecast and 300 Nm for 72 hour forecast. The method does not take into consideration effects of sudden change in the intensification of the cyclone system, which consequently extends the stormy zone of winds $\geq$34 knots. Besides, it does not account for the cyclone changes into extra-tropical stages, which also result in sudden changes of storm force winds. Additionally, it is recommended in the method description to further extend the dangerous area without specifying any values, particularly when forecasts are highly unreliable, captain and crews' experience is limited, the vessel's seaworthiness is restricted or there are other limiting factors defined by the captain. Therefore, the method does not precisely determine the area to avoid. If we combine the principle of avoiding the storm area where wind $W \geq 34$ knots with the extended zone where risk is high, we obtain a danger area to avoid by applying the 1-2-3 rule (Fig. 1) [1].

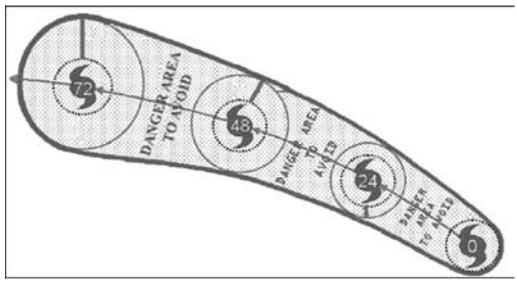

Figure 1. The 1-2-3 Rule [1].

1.2 *Calculations*

Evolutionary algorithms were used in calculations of the time-minimum route which passes by the are affected tropical cyclones [4].

The randomly chosen initial population of routes consisted of 50 individuals. The routes were processes by two operators: crossover and mutation. The number of generations amounted to 700.

As time passed by, the area threatened by tropical cyclone determined by the 1-2-3 rule increased and was treated as prohibited to navigation, which means no computing route point could appear within this field.

2 ROUTE CALCULATIONS

There were two tropical cyclones in the examined period over the North Atlantic, Gordon and Helene. The vessel began a voyage from Gibraltar to New York. Starting at 0300UTC on 15 September 2006 from position 36N/007W, the vessel headed for position 40N/073W.

Figure 2 presents the situation of the voyage beginning where the 1-2-3 rule was applied. The route is almost loxodromic one. It can be seen that only waves, having nothing to do with tropical cyclones, affect the way it runs (long distance to the cyclones, forecasts up to 72 hours are considered as prescribed by the 1-2-3 rule).

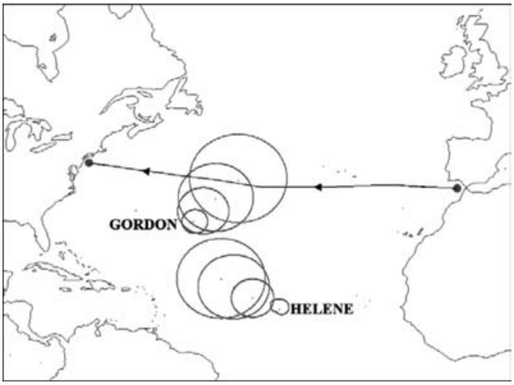

Figure 2. Vessel's position and calculated route on 15 September, 0300UTC – start of the voyage.

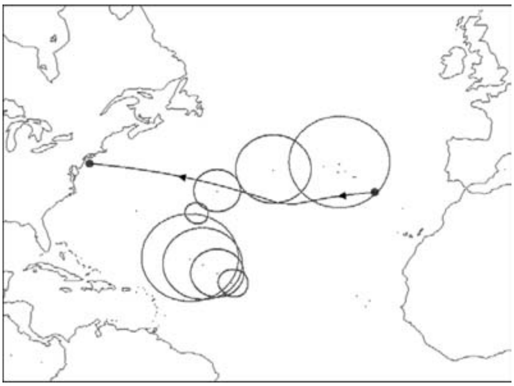

Figure 3. Vessel's position, calculated route and cyclone-threatened areas to avoid – 17 September, 0300UTC.

On 17 September at 0300UTC the vessel approached the danger area affected by tropical cyclone Gordon and avoided the storm field going south of it. Cyclone Helene then was not dangerous for the vessel (Fig. 3).

From 1500UTC 19 September the proximity of the cyclone significantly affected the calculation results and the danger area to avoid determined with the 1-2-3 method (Fig. 4).

Cyclone Gordon was out of the vessel's way at that time. The initial population of routes avoiding Helen, as shown in Figure 4, indicates there are two possible groups of routes to avoid the cyclone: northern and southern ones.

Calculations of the best track (time-minimum route) recommend avoiding the cyclone to the north (Fig. 5). The calculated route has only one point adjacent to the forecast circle of danger area ($T + 72^h$) defined by the 1-2-3 method. This, however, was not in compliance with other navigational principles; one of them says: never cross the track.

Six hours later (19 Sept at 1200UTC) calculations dramatically changed the previous decision concerning which route to choose to avoid the cyclone. Now

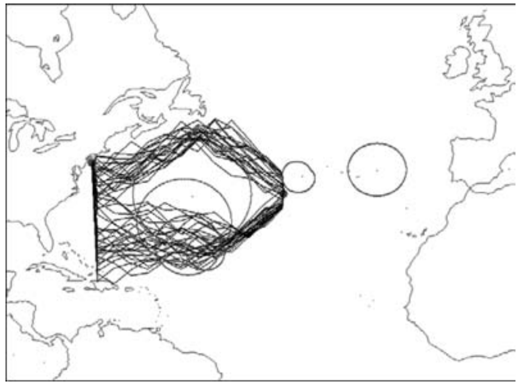

Figure 4. 19 September, 1500UTC – initial population.

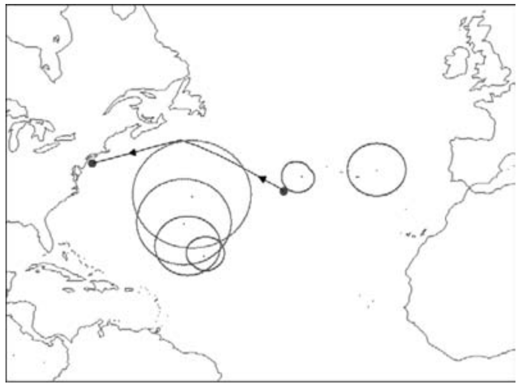

Figure 5. Vessel's position, calculated route and cyclone-threatened areas to avoid – 19 September, 1500UTC.

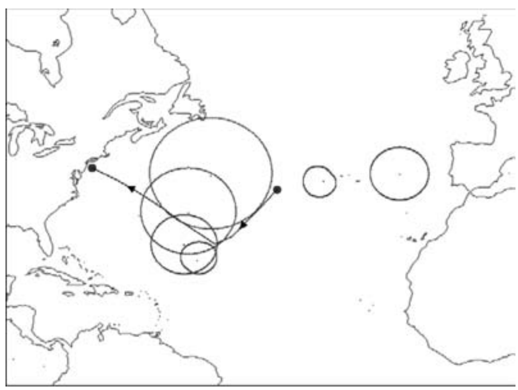

Figure 6. Vessel's position, calculated route and cyclone-threatened areas to avoid – 19 September, 2100UTC.

the vessel's track went to the south of the cyclone (Fig. 6).

This results from such factors as noticeable acceleration of cyclone Helene's speed of movement according to the latest short-term forecasts and from the range of forecasts considered in the 1-2-3 method.

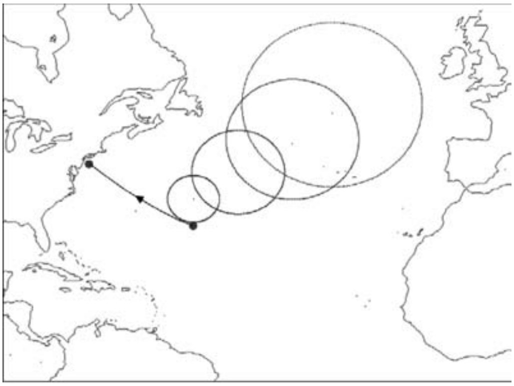

Figure 7. Vessel's position, calculated route and cyclone-threatened areas to avoid, 22 September 1500UTC.

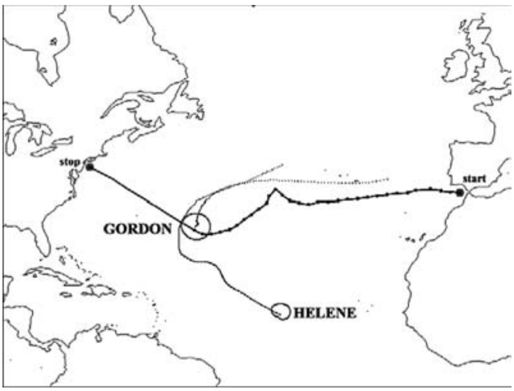

Figure 8. Final route based on 6-hour tests and the positions of cyclones Gordon and Helene at voyage start and their further movements.

Further in the course of the voyage, in tests performed every six hours, the vessel consistently avoided cyclone Helene sailing south of it, and from 1500UTC 22 September the vessel headed directly for her destination (Fig. 7).

Finally, the tested route took 254^h 12' to cover. Figure 8 shows the route together with the locations of Helene and Gordon at the start of the voyage and their further routes, worked out from real analyses.

3 THE RESULTS DISCUSSION

The test results concerning a vessel route from Gibraltar to New York, using the 1-2-3 method and actual analysis and forecast data real received onboard the vessel every six hours from 15 to 25 September 2006 will be compared to earlier results published in [5, 6]. Those studies took into account analyses that appeared after the cyclone had occurred as well as operational T+48h forecasts and available forecasts for periods up to 120 hours. The calculations using 48 h and 120 h forecasts regarded cyclone's danger area as a fuzzy domain according to the methodology found in [2, 3].

Table 1. Duration times and distances of a vessel's route for various methods of calculation.

Route calculation type	1-2-3 rule	120 h forecast fuzzy domain	48 h forecast, fuzzy domain	analysis (post fatum)
Time	254 h 12′	260 h 12′	231 h 48′	214 h
Distance	3128.4 Nm	3616.6 Nm	3260.8 Nm	3071.8 Nm

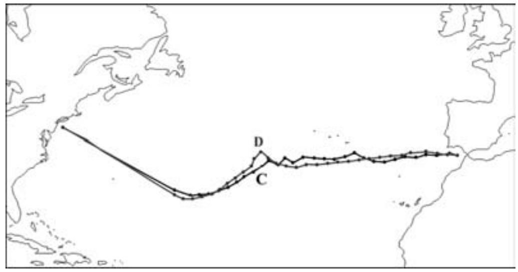

Figure 9. Route calculated using T+120h (C) forecasts and 1-2-3 rule (D).

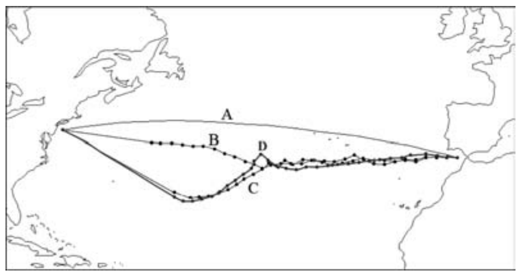

Figure 10. A – post factum route, B – 48 h forecasts and cyclone's fuzzy domain, C – 120 h forecasts and cyclone's fuzzy domain, D – 1-2-3 method.

The overall results are given in Table 1 and Figures 9 and 10.

Figure 9 compares two resultant routes, calculated using:

– the 1-2-3 method (route D),
– forecasts up to 120 h received in uptodate reports and description of the danger area with a fuzzy domain, as presented in authors' previous publication [5].

Both routes differ to some extent. The route obtained from the 1-2-3 method is shorter in terms of time by six hours and considerably shorter in terms of distance.

Knowing the results of other tests, considering only up to 48h forecasts and using analyses made after the cyclone operation, we notice significant differences in the character of routes. The considered voyage assumed the same vessel speed and accounted for the actual weather conditions and the same departure and arrival points, etc.

The application of the 1-2-3 method yields results comparable to those obtained from the method using long-term $T + 120$ h forecasts.

The danger area generated by this method, a circle increasing in time up to 72 hours until the moment the vessel comes relatively close to the cyclone, does not show substantial differences as compared to other methods.

4 CONCLUSIONS

The conclusion reached in previous publications has been confirmed. As the time horizon of forecast increases, its reliability decreases and regardless of the method used, the area of potential danger due to tropical cyclone dramatically extends in time. For the 1-2-3 method, after 72 hours this area is a circle with a 600 Nm diameter plus the forecast cyclone diameter. This hinders effective determination of routes that would not abruptly change the actual courses of vessels underway.

It seems reasonable to grade the value of unreliability of tropical cyclone area of storm depending on the time to reach it (distance, vessel's speed characteristics, weather conditions outside the cyclone area).

The 1-2-3 method should not add the values of 100, 200 and 300 Nm to the longest radius of the four quadrants of cyclone storm field. At least, it should make a difference between its two semi-circles.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

10.3 Multicriteria optimisation in weather routing

J. Szłapczyńska & R. Śmierzchalski
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The paper presents a new weather routing solution fully supporting multicriteria optimisation process of route finding. The solution incorporates two multicriteria optimisation methods, namely multicriteria evolutionary algorithm (SPEA) and multicriteria ranking method (Fuzzy TOPSIS). The paper focuses on presenting the proposed multicriteria evolutionary weather routing algorithm (MEWRA). Furthermore, it includes some experiment results together with a short description of the assumed ship model.

1 INTRODUCTION

In weather routing one is about to find the most suitable ocean's route for a vessel, taking into account changeable weather conditions and navigational constraints. One of the first approaches to the problem was a minimum time route planning based on a weather forecast called an isochrone method. The method was based on geometrically determined and recursively defined time fronts, so called isochrones. Originally proposed by R.W. James (James 1957), isochrone method was in wide use through decades. In late seventies based on the original isochrone method the first computer-aided weather routing tools were developed. However, along with computer implementation some problems arose, i.e. with so called "isochrone loops". Numerous improvements to the method were proposed since early eighties, with (Hagiwara 1989, Spaans 1986, Wiśniewski 1991) among others. Since then several different approaches to the optimisation problem was in use, with dynamic programming (Bijlsma 2004) or genetic and evolutionary algorithms (Wiśniewski et al. 2005) among others.

It is a prime goal of weather routing tools to find a route between given origin and destination ports that is the safest, the shortest and the least expensive possible. Unfortunately, these criteria are often conflicting, especially the ones expressing safety and economics. A single route, time-optimal, cost-optimal and safety-optimal at one time, hardly exists. Thus, an acceptable trade-off between the criteria is sought instead. A mathematical approach towards solving such a problem involves multicriteria (sometimes referred to as multiobjective) optimisation. Because the currently available solutions hardly apply such an approach, thus it is well-founded to propose a new multicriteria weather routing method, presented previously in (Szłapczyńska 2007).

This paper focuses on presenting a solution, implementing the multicriteria weather routing method, together with some examples of usage. The remainder of the paper is organized as follows: section 2 introduces definition of the optimisation. Section 3 provides description of a model of the researched ship. Further details on weather modelling, such as weather data sources, formats, etc., can be found in (Szłapczyńska, in press). Section 4 describes the MEWRA solution. In section 5 some examples of usage of the solution are provided. Finally, section 6 summarizes the material presented.

2 DEFINITION OF THE OPTIMISATION PROBLEM IN WEATHER ROUTING

The proposed multicriteria set of goal functions in the weather routing optimisation process, revised comparing to (Szłapczyńska 2007), is presented by equations 1–3:

$$f_{passage\_time}(t_r) = t_r \rightarrow \min \quad (1)$$

$$f_{fuel\_consumption}(q_{fc}) = q_{fc} \rightarrow \min \quad (2)$$

$$f_{voyage\_risks}(i_{risk}) = (i_{risk}) \rightarrow \min \quad (3)$$

$$i_{risk} = \frac{\sum_k (1 - i_{j\,safety})^2}{k} \quad (4)$$

where:
t_r – [h] passage time for given route and ship model,
q_{fc} – [g] total fuel consumption for given route and ship model,
i_{risk} – [/] risk coefficient for given route and the ship model,
k – [/] number of route's segments with $i_{j\,safety} < 1$,
$i_{j\,safety}$ – [/] fractional safety coefficient for (j1)th and j-th waypoints and given ship model; values of the coefficient ranges [0; 1], where 1 depicts completely

safe section of route and 0 – unacceptably dangerous section.

The assumed set of constraints in the weather routing optimisation problem includes:

– landmasses (land, islands) on given route,
– predefined minimum acceptable level of fractional safety coefficient $i_{j\ safety}$ for given route,
– floating ice bergs expected on given route during assumed ship's passage,
– predefined maximum acceptable ice concentration on given route.

The next section provides a description of a ship model and the way of modelling the goal functions (1)–(3).

3 MODEL OF THE RESEARCHED SHIP

The researched ship model (Oleksiewicz, in press) is based on a B-470 bulk carrier. Its basic parameters are shown in Table 1. The model ship is equipped with a hybrid propulsion including Sultzer RTA 48T engine and a palisade of six textile sails (Figure 1). Each sail has 522 m^2 sail surface area. The ship is equipped with a semi-adjustable B-Wageningen screw propeller.

3.1 *Modelling of passage time*

Ship speed forecast is a key element in passage time modelling. Speed characteristic of the model ship is based on algorithms presented in (Oleksiewicz, in press). Speed prognosis for the model ship is based on wind speed and wind angle forecasts. Then, speed reduction factor due to wave impact is applied to the prognosis. Detailed description on the model ship's speed modelling is given by (Szłapczyńska et al. 2007).

Table 1. Basic parameters of the model.

Parameter name	Value
Length	172 m
Width	22.8 m
Draught	9.5 m
Height	14.3 m
Service speed	15 kn
Displacement	30 288 t
Block coefficient (C_b)	0.786

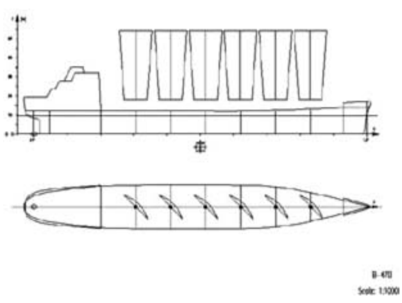

Figure 1. Sail model.

It is assumed that the ship model moves between two consecutive waypoints with constant velocity and propulsion type ("only motor engine" or "hybrid propulsion"). Thus the passage time for a route is given by:

$$t_r = \sum_{j=2..n} \frac{d_j}{v_j} \tag{5}$$

where:
t_r – [h] passage time for a route and given ship model,
n – [/] number of routes' waypoints,
v_j – [kn] speed of the ship model between (j–1)-th and j-th waypoints,
d_j – [Nm] distance between (j–1)-th and j-th waypoints.

3.2 *Modelling of fuel consumption*

Forecasted fuel consumption per hour for the ship model is calculated by:

$$FCPH = P * BSFC \tag{6}$$

where:
$FCPH$ – [g/h] fuel consumption per hour,
P – [kW] engine power,
$BSFC$ – [g/kWh] break specific fuel consumption.

Based on the model's engine (Sultzer RTA 48T) catalogue data the *BSFC* value is assumed to be 171 g/kWh. Values of engine power *P* belong to a discrete set, depending of current telegraph command, as presented in (Szłapczyńska et al. 2007).

Another aspect of fuel consumption is connected to starting the engine. Additional portion of fuel is required to every start of the engine, which might become significant when it is possible to turn the engine on and off during the voyage. Thus, the total fuel consumption of the model ship for a route is given by:

$$q_{fc} = \sum_{j=2..n} (t_j\ FCPH_j) + m\ FCPS \tag{7}$$

where:
q_{fc} – [g] total fuel consumption for given route and ship model,
t_j – [h] passage time between (j-1)-th and j-th waypoints,
$FCPH_j$ – [g/h] *FCPH* valid between (j-1)-th and j-th waypoints,
m – [/] number of engine starts,
$FCPS$ – [g] fuel consumption per start.

3.3 *Modelling of the voyage risk*

It is assumed that the wind causes the prime safety threat during the voyage. Thus, the definition of the

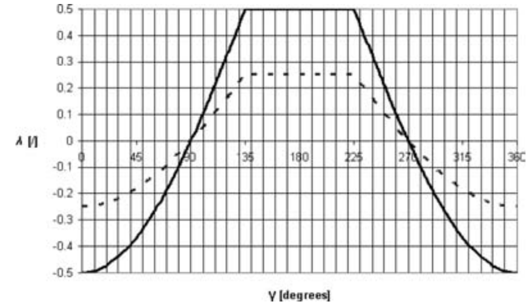

Figure 2. λ shape coefficient (solid line – hybrid propulsion; dotted line – only motor engine) as a function of wind heading angle γ.

fractional safety coefficient $i_{j\ safety}$, utilized by (4) to calculate the risk of a voyage i_{risk}, is given by:

$$i_{j\ safety} = \frac{v_{w\ \max} - v_{w\ j}}{v_{w\ \max}} \tag{8}$$

$$v_{w\ \max} = v_{\max\ def} - \lambda \Delta v_{\max\ def} \tag{9}$$

where:
$v_{w\ max}$ – [kn] maximum allowable wind speed,
$v_{w\ j}$ – [kn] wind speed between (j-1)-th and j-th waypoints,
$v_{max\ def}$ – [kn] threshold wind speed, assumed as 35 kn,
λ – [/] shape coefficient (Figure 2), dependent of the ship propulsion type and wind heading angle,
$\Delta v_{max\ def}$ – [kn] possible threshold wind speed margin, assumed as 10 kn.

The main purpose of the λ shape coefficient is to differentiate the maximum allowable wind speed $v_{w\ max}$ dependent of the wind heading angle. The coefficient discriminates (by greater λ values) mainly the following winds.

The $i_{j\ safety} = 0$ depicts a totally dangerous route sector (with $v_{w\ j} \geq v_{w\ max}$). In contrary, $i_{j\ safety} = 1$ depicts a completely safe route sector (with $v_{w\ j} = 0$).

4 WEATHER ROUTING WITH MULTICRITERIA OPTIMISATION

The proposed weather routing algorithm is based on the optimisation criteria set (1) – (3), defined in section 2. The solution utilizes two basic multicriteria mechanisms, namely multicriteria evolutionary algorithm – Strength Pareto Evolutionary Algorithm (SPEA) and multicriteria ranking method – Fuzzy TOPSIS.

4.1 *Multicriteria evolutionary weather routing algorithm (MEWRA)*

The SPEA framework in the proposed algorithm is responsible for iterative process of population development. The result of SPEA is a Pareto-optimal set of solutions. The multicriteria ranking method (Fuzzy TOPSIS) is responsible for sorting the resulting Pareto-optimal solutions according to the given preferences of the decision-maker. The preferences are represented by linguistic values with fuzzy weights assigned to the decision criteria. The main algorithm's flow is illustrated in Figure 3.

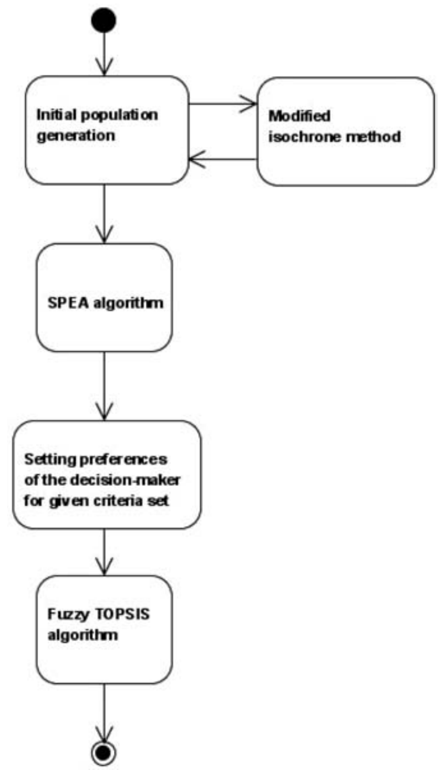

Figure 3. Multicriteria evolutionary weather routing algorithm.

4.2 *Chromosome structure*

An individual in the evolutionary approach, also referred to as a solution, represents a route. The route includes an array of waypoints constituting ship's trajectory, where the first one is equal to the position of the origin port and the last one – to the destination port. A single entry of the waypoints array includes:

- geographical coordinates (longitude, latitude) of the waypoint,
- motor engine relative settings valid from the previous to the given waypoint, ranging [0;1],
- propulsion type (there are two different propulsion modes distinguished for the assumed ship model: "motor only" and "motor & sails"),
- time of reaching given waypoint,
- velocity of the ship, assumed constant on a sector between two waypoints, valid from the previous to the given waypoint,
- uncertainty index for given waypoint (value representing uncertainty of the waypoint's data).

Only the first three elements of the waypoint entry are in direct control of the evolutionary mechanisms: the coordinates, motor settings and propulsion type. All the other values can be calculated as functions of the former and are stored in the chromosome in order to improve on efficiency of the algorithm.

4.3 *Initial population*

The first step towards evolutionary computation is always building an initial population. In the considered weather routing case, a preliminary set of basic routes is generated at first. For given pair of origin and destination ports the set includes the following routes:

- an orthodrome,
- a loxodrome,
- a time-optimized isochrone route (Spaans 1986, Hagiwara 1989, Wiśniewski 1991), referenced further as IZO_REF_TIME,
- a route given by fuel-optimization applied to the time-optimized isochrone route, referenced further as IZO_REF_FUEL.

The isochrone routes (IZO_REF_TIME & IZO_REF_FUEL) are generated with time step 2 h.

The initial population is generated by creating random mutations of the basic routes. Also pure basic routes are included in the initial population.

4.4 *Specialized operators*

There are several specialized "genetic" operators required by the evolutionary framework, each customized to the established chromosome structure. The set of specialized operators in the multicriteria evolutionary weather routing algorithm includes:

- one-point crossover,
- non-uniform mutation,
- route smoothing by means of average weighting.

4.5 *Final ranking of routes*

When SPEA completes its computations, the available result set includes the Pareto-optimal set of individuals (routes) and a corresponding Pareto front. Unfortunately (or fortunately, but from the other perspective) the Pareto-optimal set is numerous. Thus it would be inconvenient for the user (e.g. a captain) to browse manually through the complete set of resulting routes in search of the most suitable one.

Yet another problem might be encountered: how to decide which route is the best within given multicriteria optimisation environment? To solve this problem decision-maker's (e.g. captain's) preferences to the given criteria set should be defined. Hence a tool for sorting the Pareto-optimal set is provided – Fuzzy TOPSIS method. The method creates a ranking of routes based on the decision-maker's preferences expressed by linguistic values with triangular fuzzy values assigned (Table 2). The decision-maker picks one linguistic variable per criterion. The variable should describe the most accurately the significance of the criterion and its impact on the decision. The first route in the final ranking will be the most suitable one from the Pareto-optimal set, with reference to the previously defined preferences to the criteria set.

Table 2. Linguistic values and corresponding triangular fuzzy values, utilized to express decision-maker's preferences to the criteria set.

Linguistic value	Triangular fuzzy value
very important	(0.7; 1.0; 1.0)
important	(0.5; 0.7; 1.0)
quite important	(0.2; 0.5; 0.8)
less important	(0.0; 0.3; 0.5)
unimportant	(0.0; 0.0; 0.0)

Table 3. Linguistic values assigned to the criteria set in the multicriteria evolutionary weather routing algorithm.

Route description	Passage time	Fuel consumption	Voyage risk
MEWRA_TIME	very important	unimportant	unimportant
MEWRA_FUEL	unimportant	very important	unimportant
MEWRA_ COMPROMISE	important	less important	very important

5 EXAMPLES OF USAGE

This section presents two experiment results with the proposed multicriteria evolutionary weather routing algorithm. The experiments' origin and destination ports as well as the departure dates vary to present performance of the algorithm for various weather conditions. In both cases output of the algorithm is compared with the routes found by the time-optimised and fuel-optimised isochrone method respectively. Output routes of the multicriteria evolutionary weather routing algorithm (depicted as MEWRA) were selected by means of linguistic values assigned to the criteria set as given in Table 3.

5.1 *Lisbon – Miami, departure 2008-09-02 at 00:00*

The initial population generated for the Lisbon-Miami voyage is presented in Figure 4. The set of Pareto-optimal solutions (routes), obtained after 100 of generations during evolutionary optimisation, is then presented in Figure 5. The resulting MEWRA_TIME, MEWRA_FUEL and MEWRA_COMPROMISE routes are then presented by comparison to the isochrone routes in Figure 6–8 respectively. Basic performance parameters of the

Figure 4. Initial population of routes for Lisbon-Miami voyage, departure 2008-09-02 00:00.

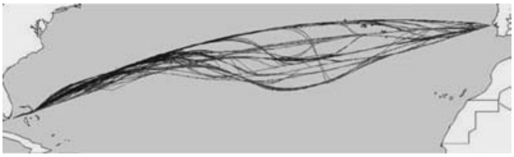

Figure 5. Set of Pareto-optimal routes for Lisbon-Miami voyage, departure 2008-09-02 00:00.

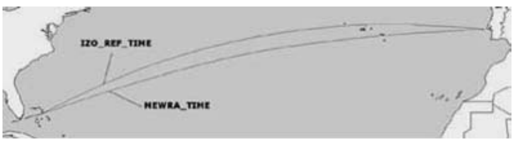

Figure 6. Output of the algorithm MEWRA_TIME compared to the time-optimal isochrone route for Lisbon-Miami voyage, departure 2008-09-02 00:00.

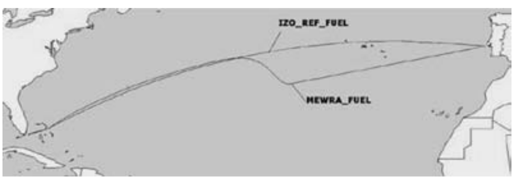

Figure 7. Output of the algorithm MEWRA_FUEL compared to the fuel-optimal isochrone route for Lisbon-Miami voyage, departure 2008-09-02 00:00.

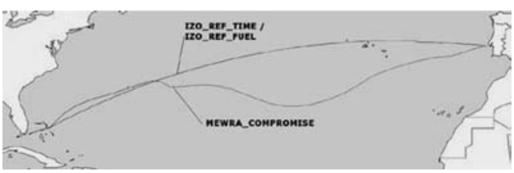

Figure 8. Output of the algorithm MEWRA_COMPROMISE compared to the time-optimal and fuel-optimal isochrone routes for Lisbon-Miami voyage, departure 2008-09-02 00:00.

MEWRA and reference isochrone routes are collated in Table 4.

During the period of 2008-09-01 and 2008-09-15 the Tropical Weather Outlook of National Hurricane Centre reported activities of three tropical storms and cyclones in Atlantic region, namely Hanna, Ike and

Table 4. Comparison of basic performance parameters of the reference isochrone routes and output of the algorithm (MEWRA routes) for Lisbon-Miami voyage, departure 2008-09-02 00:00.

Route description	Passage time [h]	Fuel cons. [t]	Voyage risk [/]	Avg speed[kn]
IZO_REF_TIME	234.29	308.81	0.149	15.37
IZO_REF_FUEL	531.56	48.36	0.124	6.77
MEWRA_TIME	233.30	307.50	0.132	15.49
MEWRA_FUEL	373.54	8.45	0.094	10.24
MEWRA_ COMPROMISE	288.91	225.79	0.058	13.51

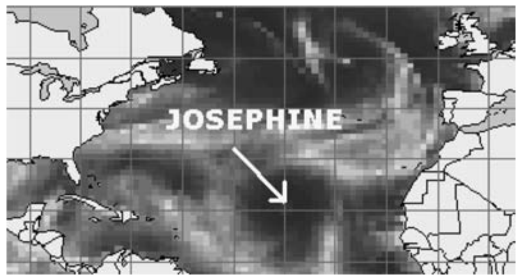

Figure 9. Wind speed forecast (NOAA Wave Watch III) on 2008-09-10 for the Northern Atlantic region with indicated position of tropical depression Josephine.

Josephine. However, the considered routes were threatened directly with Josephine only. The outlook of wind speed forecast (NOAA Wave Watch III) on 2008-09-10 is presented in Figure 9. The remnant low of Josephine continued moving to the west for the next several days.

As depicted by the Figure 5, all the Pareto-optimal routes bypass Josephine. The MEWRA_TIME route compared to the time-optimal isochrone route (IZO_REF_TIME) is shorter almost 1h, requires over 1.3t less fuel and is safer (lesser voyage risk factor) the same time. The similar tendencies can be found for the MEWRA_FUEL and IZO_REF_FUEL pair of routes. But this time passage time saving in almost 30%, fuel saving exceeds 80% and voyage risk is reduced by almost 25%. The MEWRA_FUEL route owes its supremacy the utilization of favourable winds with possibility to turn off the engine. Another aspect of the supremacy is that the IZO_REF_FUEL route is not a fully fuel-optimized one (it is a fuel-optimized time-optimal isochrone route). Due to that it is better to compare MEWRA_FUEL with IZO_REF_TIME. In such case fuel reduction exceeds 97% and voyage risk reduction is almost 37%, but for the cost of increasing passage time by almost 60%. On the other hand, the MEWRA_COMPROMISE route allows reduction of the risk factor by 60% (mostly due to bypassing the remnant of Josephine by means of "34 knot wind radius rule") comparing with IZO_REF_TIME. The route allows over 26% fuel saving for cost of increasing passage time by less than 24%.

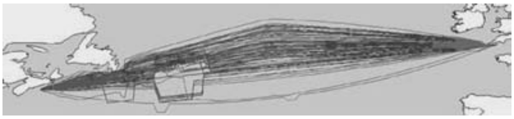

Figure 10. Initial population of routes for Halifax – Plymouth voyage, departure 2008-02-15 12:00.

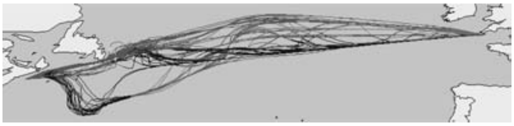

Figure 11. Set of Pareto-optimal for Halifax – Plymouth voyage, departure 2008-02-15 12:00.

Figure 12. Output of the algorithm MEWRA_TIME compared to the time-optimal isochrone route for Halifax – Plymouth voyage, departure 2008-02-15 12:00.

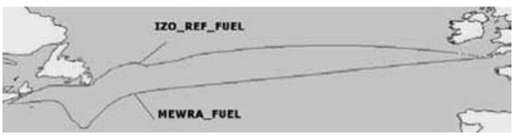

Figure 13. Output of the algorithm MEWRA_FUEL compared to the fuel-optimal isochrone route for Halifax – Plymouth voyage, departure 2008-02-15 12:00.

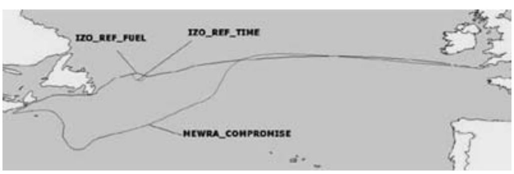

Figure 14. Output of the algorithm MEWRA_COMPROMISE compared to the time-optimal and fuel-optimal isochrone routes for Halifax – Plymouth voyage, departure 2008-02-15 12:00.

5.2 *Halifax – Plymouth, departure 2008-02-15 at 12:00*

The initial population generated for the Halifax – Plymouth voyage, is presented in Figure 10. The set of Pareto-optimal routes, obtained after 100 of generations, is then presented in Figure 11. The resulting MEWRA_TIME, MEWRA_FUEL and MEWRA_COMPROMISE routes are presented by Figures 12–14 respectively. Basic performance parameters of the MEWRA and reference isochrone routes are collated in Table 5.

During the period of 2008-02-15 and 2008-02-28 neither tropical storms nor cyclones were reported by NHC. However, strong wind fields originating on US Atlantic coast, heading towards eastern coast of Greenland, were expected repeatedly during the period. A non-zero ice concentration was observed during the period at northern coast of New Funland. Also rare icebergs transported by Labrador Current were expected in the area.

Table 5. Comparison of basic performance parameters of the reference isochrone routes and output of the algorithm (MEWRA routes) for Halifax – Plymouth voyage, departure 2008-02-15 12:00.

Route description	Passage time [h]	Fuel cons. [t]	Voyage risk [/]	Avg speed[kn]
IZO_REF_TIME	157.89	208.14	0.290	15.58
IZO_REF_FUEL	420.84	14.77	0.312	5.75
MEWRA_TIME	152.99	201.68	0.340	15.62
MEWRA_FUEL	259.66	1.23	0.245	10.25
MEWRA_ COMPROMISE	206.34	191.98	0.159	14.03

The Pareto-optimal routes (Figure 11) avoid the strong wind fields as well as the ice threat zone. The MEWRA_TIME route compared with the IZO_REF_TIME is shorter by almost 5 h, requires over 6t less fuel for a cost of slightly higher voyage risk (less than 18%). On the other hand the MEWRA_FUEL route compared to IZO_REF_FUEL is significantly shorter (over 38%), allows enormous reduction of fuel consumption by over 91% and also improves route's safety (voyage risk reduced by over 21%). Again, when compared to IZO_REF_TIME, the MEWRA_FUEL achieves almost 99.5% of fuel reduction and 15% voyage risk reduction, but for the cost of almost 65% longer passage. On the other hand, the MEWRA_COMPROMISE route allows further minimization of the risk factor, with 45% reduction of the factor (due to bypassing strong wind fields on the south from New Funland) comparing with IZO_REF_TIME. The route allows 7% fuel saving with passage time increased by less than 31%.

6 CONCLUSION AND FUTURE WORK

The proposed multicriteria evolutionary weather routing algorithm (MEWRA) was presented here in application to the hybrid propulsion ship model. With MEWRA it was possible to obtain significant reductions of passage time, fuel consumption and risk factor, however (time in most cases) not all at the same. Based on the results presented in the previous section, the following tendencies can be observed:

– MEWRA_TIME routes, when compared with the time-optimal isochrone routes (IZO_REF_TIME), slightly shorten passage time (0.5% & 3.1%) and reduce fuel consumption (0.5% & 3.1%), but in one out of two cases may increase voyage risk (here: by 18%). The similar percentage values of passage time and fuel consumption reduction depict that the fuel savings are caused by the shortened passage only. The average service speed on MEWRA_TIME is 3.5% – 4.1% greater than the original service speed.

- MEWRA_FUEL routes, when compared with the fuel-optimized time-optimal isochrone routes (IZO_REF_FUEL), significantly shorten passage time (30% & 38%), reduce fuel consumption (80% & 91%) and decrease voyage risk (21% & 25%). The surprisingly good MEWRA passage time performance is caused here by the fact that the IZO_REF_FUEL route is suboptimal. Fuel consumption reductions are caused by the possibility of turning the engine off during the voyage. The average speed on MEWRA_FUEL routes is 30% – 35% lesser from the original service speed.
- MEWRA_FUEL routes, when compared with the time-optimal isochrone routes (IZO_REF_TIME), even more significantly reduce fuel consumption (97% & 99.5%) and decrease voyage risk (15% & 37%). The lengthened passage time (60% & 65%) is the cost of the savings in this case. Such a good MEWRA fuel consumption performance is caused, again as in previous comparison, by the very nature of the hybrid propulsion model. Allowing, during the voyage, the possibility of turning the engine off and finding the best possible wind conditions, one (at least theoretically) is able to achieve 100% fuel reduction. The question is, whether it is acceptable to drastically lengthen the passage to achieve such fuel savings.
- MEWRA_COMPROMISE routes try to establish a practical trade-off between the basic routes' parameters. The routes, when compared with the time-optimal isochrone routes (IZO_REF_TIME), significantly reduce voyage risk (45% & 60%) due to bypassing the main encountered security threats. The routes also reduce fuel consumption (7% & 26%), but lengthen the passage time (24% & 31%). Actions taken to increase routes' safety are the major factors inducing longer passage. The average speed of MEWRA_COMPROMISE is only 6.4% – 10% lesser from the original service speed.

To conclude, MEWRA is a new weather routing solution and, as proved by the experiment results, competitive towards other single-objected methods, such as e.g. the isochrone method. The solution expands functionality of typical weather routing tools by introducing the trade-off routes (MEWRA_COMPROMISE), yet preserving the possibility to search for single-objected routes (MERWA_TIME & MEWRA_FUEL). In addition to that, it is possible to define another set of result routes by assigning simple linguistic values (such as "important", "less important" or "unimportant") to each of the optimisation criterion.

It is worth mentioning that MEWRA execution time in the both presented cases (Lisbon – Miami & Halifax – Plymouth) was shorter than 20 min. The execution times seem to be acceptable, taking into account the future plans to improve MEWRA towards dynamic route update mechanisms. Other plans include expanding MEWRA to support a custom ship model with traditional motor engine.

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10.4
On the fuel saving operation for coastal merchant ships using weather routing

K. Takashima & B. Mezaoui
Graduate School, Tokyo University of Marine Science and technology, Tokyo, Japan

R. Shoji
Tokyo University of Marine Science and technology, Tokyo, Japan

ABSTRACT: It is well known that Weather Routing is one of the effective ship operation methods to reduce fuel consumption and many studies have been conducted to develop the effective calculation methods. However, most studies were performed focusing on the ocean going ships, and there were few studies made for coastal ships. The authors propose a minimum fuel route calculation method for coastal ships that use the precise forecasted environmental data and the propulsion performance data of the ship on actual seas. In the proposed method, we use the Dijkstra's algorithm to calculate an optimum minimum fuel route suitable for coastal ships. Simulation study was carried out to evaluate the effectiveness of the proposed method using two coastal ships. As the result of study, the authors confirmed that the proposed calculation method is effective for fuel consumption reduction and is applicable for the operation of coastal merchant ships.

1 INTRODUCTION

In the late years, the ship operation cost increased due to the raise of oil prices and the reduction of CO_2 and NO_x gas emission have become a urgent matter to protect the environment.

Up to now, various researches on the weather routing (here after WR) had been conducted and various calculation methods were developed in order to find the safest route, shortest time route, minimum fuel route. But until now WR researches are performed focusing on the operation of ocean going ships. Being mainly developed for long voyages with a wide choice of routes, WR cannot be directly applied for ships sailing on confined coastal water (Haibo 2005).

In the recent years there have been tremendous advances in weather forecasting techniques, forecast of current also greatly progressed. Taking advantages of these progresses we developed a routing method with minimum fuel consumption for coastal ships.

In this paper we present a method for calculating the minimum fuel consumption route (here after MFR) for a specified voyage time for coastal ships using precise weather forecast data and ship's performance model, the results of the simulation study with this calculation method will also be discussed.

2 CALCULATION OF MINIMUM FUEL ROUTE USING DJIKSTRA'S ALGORITHM

For calculating the minimum fuel route, Djisktra' s algorithm was used. This algorithm was developed by Edsger W. Dijkstra in 1959; it is one of the most common algorithms for solving the shortest path problem, it finds the shortest path from a single source vertex to other vertices in a graph that is weighted (non negatively weighted), directed and connected.

Setting the departure point as P_0 and the destination point as *Ps*, the standard route from P_0 to *Ps* is constructed. A set of vertex (nodes) is constructed on the perpendicular to the standard route (hereafter we call all the nodes lying on the same perpendicular from the standard route "vertex line") (Takashima 2008).

The distance between the vertex lines is a function of the ship's type and average speed and can be easily changed to accommodate the type of voyage; the distance between each vertex on a vertex line is set to 2 miles in this work but it can also be changed.

In the method, we propose the propeller revolution number is kept constant during the voyage and only the course can be controlled, which is more in accordance with the practice onboard ship where propeller revolution number is not constantly being changed but kept constant and the course is gradually adjusted.

The propeller revolution number is determined so as to reach the destination point at the desired time of arrival. We will look for the minimum propeller revolution number that will allow us to reach the destination at the desired time of arrival, by doing so we will find the most practical minimum fuel route for the desired voyage time.

Ship's position can be described by the following equation:

$$x = f(t, x, S, C) \tag{1}$$

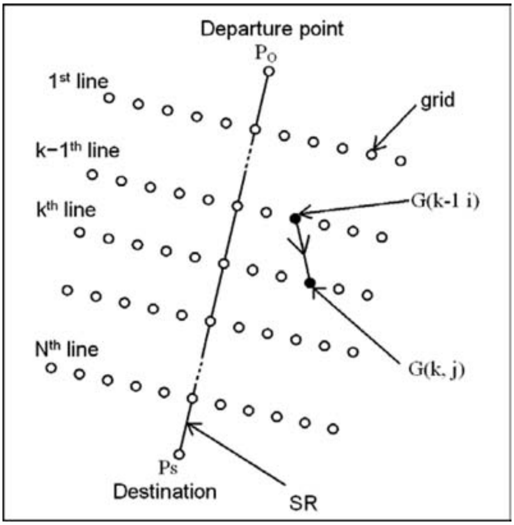

Figure 1. Grid points of DP to calculate minimum fuel route.

Where t is the time, x the position of the ship, S the speed and C the control parameter, which in our case is dependent only on rudder angle since the propeller revolution number in kept constant.

The speed of the ship at any instant is function of ship's heading and response to the external weather elements, such as wave, wind and current.

$$S = f(\theta, wave, wind, current) \quad (2)$$

Knowing the weather elements we can determine the speed of the ship, and knowing this later allows us to compute the time needed to travel from one node to another.

Let the i-th node on the k-th vertex line from P_0 be $G(k, i)$. The ship starts from $G(k, i)$ at time t_k and reaches the node $G(k-1, j)$ on the $k-1$-th vertex line at time t_{k-1} (see fig.1 for more details).

The minimum time route from the departure point P_0 to the destination Ps is obtained by solving the following iterative equation:

$$T_{\min}(G(k,i)) = \underset{j}{Min}\{T(G(k-1,j),G(k,i)) + T_{\min}(G(k-1,j))\} \quad (3)$$
$$(k=1,2,\ldots,N+1)$$

Where T_{min} $(G(k, i))$ represents the minimum passage time from the departure P_0 to the node $G(k, i)$, and $T(G(k\text{-}1, j), G(k, i))$ represents the passage time from the previous node $G(k-1, j)$ to the node $G(k, i)$.

Eq.3 means than the minimum passage time from departure point P_0 to any point $G(k, i)$ can be determined by finding the minimum of the sum of passage time from $G(k-1, j)$ to $G(k, i)$ and the minimum passage time from departure point P_0 to $G(k-1, j)$ (when k reaches $N+1$, $G(N+1)$ is Ps).

If the T_{min} obtained by solving (3) is not equal to the desired voyage time the propeller revolution number is changed and (3) resolved, we will gradually adjust the propeller revolution number until we get a T_{min} as close as possible to the desired voyage time.

The route thus obtained can be considered as the minimum fuel route for the specified voyage time. Here after we will refer to this route as MFR.

The MFR obtained by this method is not the true minimum fuel route from the mathematical point of view, but it can be regarded as the sub-optimal route that will allow us to reach destination at the desired time with a minimum consumption and a fixed propeller revolution number. In this method since the only control parameter is the ship's course the amount of calculation is largely reduced

3 ENVIRONMENTAL DATA

The environmental data used for carrying simulation with this calculation method are forecasted data of surface winds, waves, ocean and tidal currents, these data were used to calculate the ship's speed trough the water and over the ground. The forecast data are available for each 1 hour, extending for a period of 72 hours, the forecast data are updated 8 times a day (i.e. base time of forecast: 00,03,06,09,12,15,18,21 UTC).

3.1 *Wind and wave data*

The wind data comprises mean wind direction and mean wind speed; the wave data comprises the significant wave height, predominant wave direction and significant wave period.

For the forecast period up to 15 hours ahead the forecasted data are the result of the input of the surface winds from the mesoscale numerical forecast model of the Japan Meteorological Agency into the 3rd generation wave forecast model "WAM" of the Japan Weather Association, the data are given for grids of 2 by 2 miles.

For the forecast period from 16 to 72 hours ahead, the data are from the output of the wave forecast model of the Japan Meteorological Agency, the data are given for grids of 6 by 6 miles.

3.2 *Ocean and tidal current data*

The ocean current forecasted data are the output from the Japan Coastal Predictability Experiment operated by Frontier Research Center for Global Change; the data are given for grids of 5 by 5 miles.

The Tidal current forecasted data are from the output of the tidal calculation program developed by the National Astronomical Observatory of Japan. The data are given for grids of 2 by 2 miles. The data are given for grids of 2 by 2 miles

4 SPEED AND ENGINE PERFORMANCE IN SEAWAY

Two ships, A roll-on/roll-off container ship plying between Tokyo and Tomakomai/Kushiro in Hokkaido

Table 1. Principal particulars of the model ship-A.

Length over all	161.13 m
Length between perpendiculars	150.00 m
Breadth	24.00 m
Full load draught	6.424 m
Gross tonnage	7,323 ton
Engine type	Diesel engine × 1
Max engine power	16,920 kW
Normal engine power	14,380 kW
Sea speed	23.00 kn
Carrying capacity	50 trailers (12 m) 200 containers (12 feet)

Table 2. Principal particulars of the model ship-B.

Length over all	159.7 m
Length between perpendiculars	152.5 m
Breadth	24.2 m
Full load draught	9.016 m
Gross tonnage	13,787 ton
Engine type	Diesel engine × 1
Max engine power	6,960 kW
Sea speed	13.0 kn

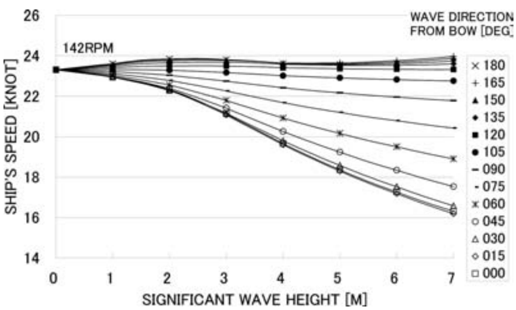

Figure 2. Speed performance curve of model ship-A at 142 RPM.

(north of Japan) and a cement career plying between Ube in Yamaguchi (south-east of Japan) and Tokyo were used for the simulation to investigate the effectiveness of the proposed minimum fuel route calculation method, hereafter we refer to the Ro/Ro container ship as "model ship-A" and to the cement carrier ship as "Model ship-B". The principal characteristics of the two ships are shown in Table 1 and Table 2.

The speed through the water of the two ships was calculated by numerically solving the equilibrium equation between total resistance (sum of the still water resistance, the wind resistance and the added resistance due to waves) and the propeller thrust (Kano 2008). For various rpm, wind conditions and wave condition we get the corresponding speed through the water. In figure 2 and 3, speed performance curve 142 rpm (for model ship-A) and 157 rpm (for model ship-B) for various wave heights and wave direction from the bow are shown. When drawing these curves,

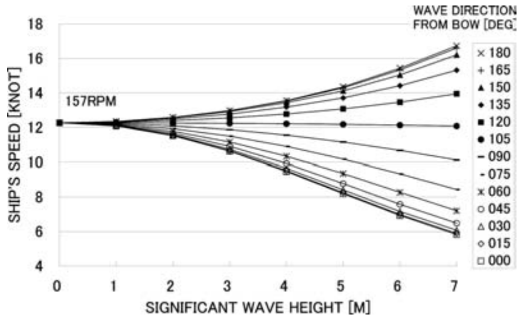

Figure 3. Speed performance curve of model ship-B at 157 RPM.

the wind speed (m/s) was taken to be four times the significant wave height (m), the wind direction was assumed to be equal to four times the square root of the significant wave height. It can be clearly seen that the speed reduction increase with the decrease of the wave direction from the bow. In the elaboration of these performance curves, operational limits due to excessive ship's motion and accompanying dangerous phenomena are not considered when elaborating these curves.

The fuel consumption F in kg per hour of the model ship is calculated using the following equation

$$F = KP \tag{4}$$

Where K is the specific fuel consumption of the ship (for model ship-A, $K = 0.180$ kg/kW h, for model ship-B, $K = 0.182$ kg/kW h) and P is the engine power in BHP (kW) of the model ship.

5 RESULTS OF MFR SIMULATION

We conducted MFR simulation for the two ships (model ship-A and model ship-B) using the proposed calculation method. For demonstrating the effectiveness of the proposed calculation method, we also simulated the fuel consumption for the route usually used by the ship (hereafter UR). A suitable propeller revolution number is set, the propeller revolution number is set to be constant during the voyage, according to this and using the environmental data, speed and engine performance data, the voyage time is calculated.

If the voyage time is not close to the desired voyage time, the propeller revolution number is changed and the voyage time recalculated, the calculation will be stopped when the difference between the calculated voyage time and desired voyage time reaches ±0.1 hour. The fuel consumption thus obtained is assumed to be the UR fuel consumption.

The simulation has been conducted for the condition shown as follows.

Model ship-A

– Route: From Kushiro to Tokyo (South bound)
– Term of simulation: November 2008
– Departure time: at 15:00(UTC) on each day

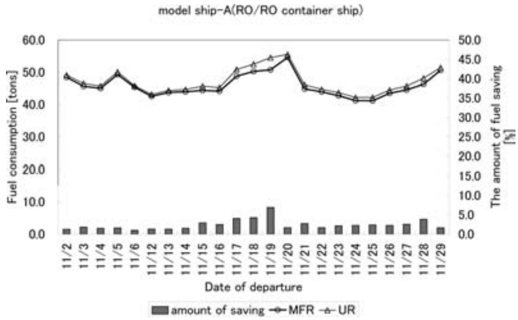

Figure 4. Fuel consumption and fuel saving amount for model ship-A.

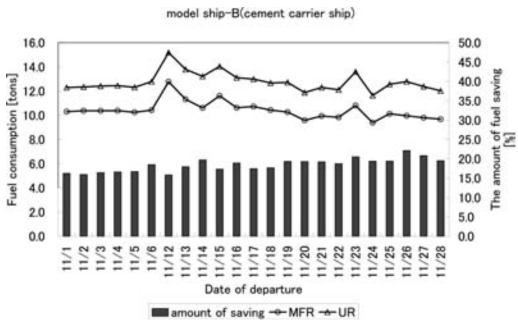

Figure 5. Fuel consumption and fuel saving amount for model ship-B.

– desired voyage time: 26 hours

Model ship-B

– Route: From Ube to Tokyo (East bound)
– Term of simulation: November 2008
– Departure time: at 15:00(UTC) on each day
– desired voyage time: 29 hours

5.1 *Comparison of fuel consumption in MFR and UR*

For achieving a good comparison between the MFR and UR fuel consumption it would be better to use weather data with as small error as possible. For achieving this, we use only the first three hour forecast data of each weather forecast report, hereafter we refer to this data as Analyzed Wx and to the original data as Forecast Wx.

Using the Analyzed Wx, we simulated MFR and UR fuel consumption for 1 month (November 2008). The results for ship model-A and ship model-B are shown in figure 4 and 5 respectively.

The O marked curve shows MFR fuel consumption, the Δ marked curve shows the UR fuel consumption and the bar graph represents the saving of fuel between the two routes.

For both model ships, there is an evident fuel saving between MFR and UR; for model ship-A the average saving is 2.4%, the largest is 6.9%; for model ships-B the average saving is 18.4% and the largest saving amount is 22.1%.

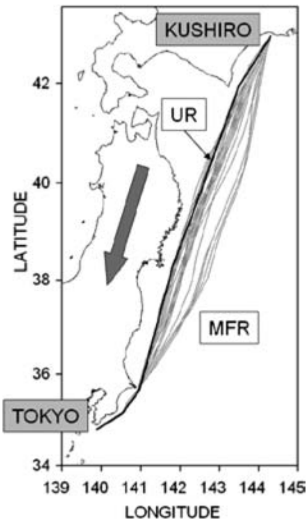

Figure 6. Comparison between MFR ad UR for November 2008 for model ship-A.

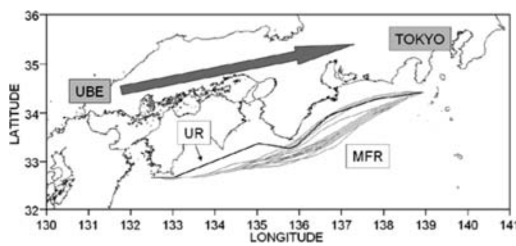

Figure 7. Comparison between MFR ad UR for November 2008 for model ship-B.

The MFR routes obtained are shown on figure 6 for ship model-A and figure 7 for ship model-B, we an notice that the MFR tends to be farther from the coast line than the UR.

Figure 8 and 9 show the sea current data for the voyages with the largest amount of fuel saving. We can notice that the MFR avoids regions with opposite current and takes advantage of the regions where current flows in the same direction as the ship's route. We also compared the difference between the speed over ground and speed through the water for the MFR and the UR, for the MFR, nearly all along the voyage the speed over ground is higher that speed through the water, which demonstrates that the MFR is the route that takes advantage of the ocean and that for the Japanese coasts, the ocean current has a large influence on fuel saving.

5.2 *Recalculation of MFR using updated environmental forecast*

Practically using Analyzed Wx for the calculation is impossible; In fact there is a time lag of about 9 hours

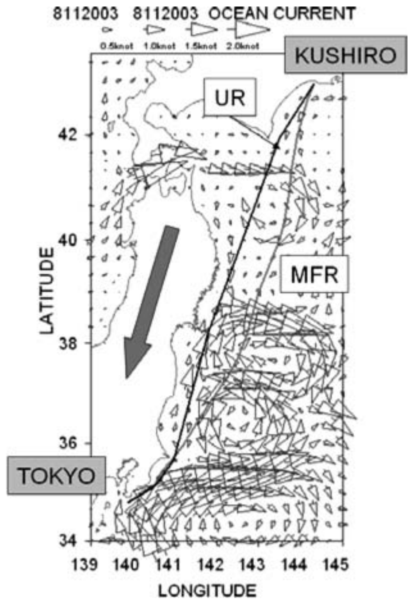

Figure 8. Ocean current data for 20/12/2008.

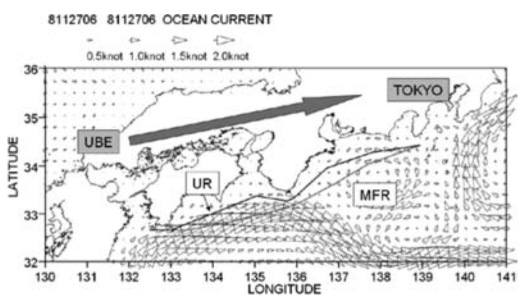

Figure 9. Ocean current data for 27/12/2008.

between the forecast and its publication, so at any time only the forecast Wx data is available, the Analyzed Wx data will not be available until the time lag has passed, which means it can not be really used for calculation.

Using the latest available Forecast Wx data, we calculated the MFR for model ship-A, the departure time is 17/12/2008 at 15:00 UTC from Kushiro in Hokkaido to off Tokyo.

Hereafter we call the MFR obtained using the Forecast Wx data as MFR-F and the MFR obtained using Analyzed Wx data as MFR-A.

We can notice from figure 10 that shows both routes, that the MFR-F tends be farer from the coast than the MFR-A and this due to the error in the forecast; we checked the accuracy of weather forecast data and found that the Forecast Wx wind data tends to be smaller than the Analyzed Wx wind data.

To palliate the error on the route generated this error on the forecast, we use rerouting; rerouting consists on recalculating a new route from the present position to the destination point every time there is a change in the weather data, the ship starts from the departure

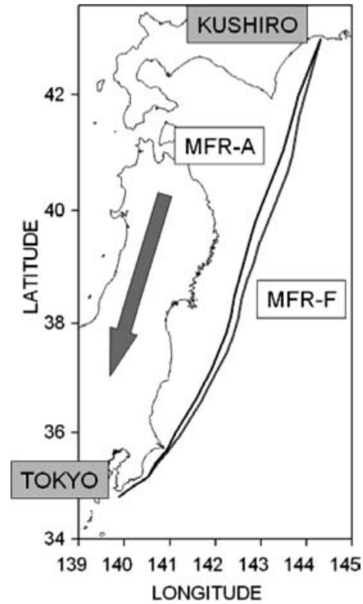

Figure 10. Comparison between MFR obtained using only Analyzed Wx data and using Forecast Wx data.

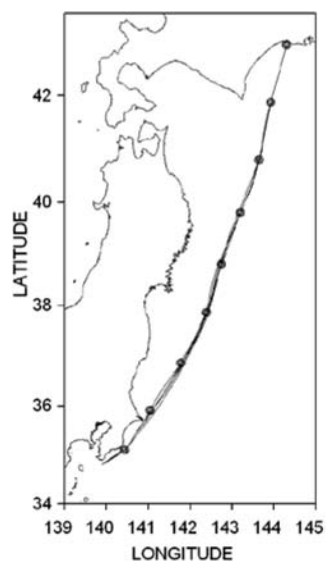

Figure 11. MFR obtained using Forecast Wx data with recalculation every 3 hours.

point and sails on the MFR calculated using the available Forecast Wx data, when a new weather forecast is available the MFR is recalculated from the actual position of the ship to the destination point using the newly available data.

Figure 11 shows the simulation of the MFR obtained using forecasted data updated every three hours. The rerouting points are shown with O marks, the rerouting has been done 9 times in this voyage.

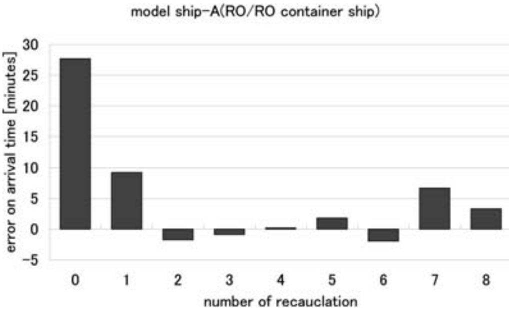

Figure 12. Error of arrival time with regards to the number of recalculation.

We also calculated the difference on arrival between the MFR-A and the MFR-F calculated on each rerouting. If the ship arrives ahead of the desired time the error is deemed positive and it arrives late the error is negative.

Figure 12 shows the error on arrival time with regards to the number of rerouting calculation, without any rerouting the error on arrival time is around +28 minutes, with one rerouting recalculation the error decreases to +9 minutes and with a maximum number of recalculation the error is around +3 minutes.

Using rerouting calculation the error on arrival time can be reduced to an acceptable value.

6 CONCLUSIONS

In this paper, a method for achieving energy saving for coastal merchant ships using weather routing was proposed. An optimization method based on Dijkstra's algorithm using weather forecast data was proposed. Two ships, one is a RO/RO container ship plying between Kushiro in north Japan and Tokyo, another is a cement carrier plying between Ube in west Japan and Tokyo were taken as models, the speed and engine performances in waves of both ships were determined, simulations were also conducted.

The results of one month simulation shows that the MFR obtained using the proposed calculation method allows to save a large amount of fuel, the average saving for two model ships is 2.4% and 18.4%, the maximum saving is 6.9% and 22.1% respectively.

There is a strong oceanic current along the Japanese coast, the proposed MFR calculation method, takes advantage of this current and achieves a good energy saving.

Recalculation of the MFR based on the updated weather forecast data during the voyage allows to reduce the effect of the forecast error.

For the further development of this research, a concept of risk of delay will be introduced to the calculation algorithm, using the information on the accuracy of wind/wave forecast, the possible error on the arrival time is determined and a minimum fuel route arriving at the destination point with a specific probability of the risk of delay can be calculated.

This study was done as a part of the "Research and Development of Environment-Harmonized Operation Planning Support System for coastal ships" by New Energy and Industrial Technology Development Organization (NEDO).

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10.5 Solving multi-ship encounter situations by evolutionary sets of cooperating trajectories

R. Szłapczyński
Gdańsk University of Technology, Gdańsk, Poland

ABSTRACT: The paper introduces a new approach to solving multi-ship encounter situations by combining some of the assumptions of game theory with evolutionary programming techniques. A multi-ship encounter is here modelled as a game played by "thinking players" – the ships of different and possibly changing strategies. The solution – an optimal set of cooperating (non-colliding) trajectories is then found by means of evolutionary algorithms. The paper contains the description of the problem formulation as well as the details of the evolutionary program. The method can be used for both open waters and restricted water regions.

1 INTRODUCTION

The two main approaches to the problem of determining optimal ship trajectories in encounter situations are the methods based on either differential games or evolutionary method. The methods based on differential games were introduced by Lisowski (Lisowski, 2005). They assume that the process of steering a ship in multi-ship encounter situations can be modelled as a differential game, played by all ships involved, each having their strategies. The game is differential, since it describes the dynamics and kinematics of all ships. The method's main limitations include the high computational complexity and difficulties in handling the stationary obstacles and ship domains other than a circle (its radius being the safe distance).

The second approach – the evolutionary method of finding the trajectory of the own ship has been developed by Śmierzchalski (Śmierzchalski, 1998). It has been among the first methods that utilized the concept of a ship domain instead of safe distance between ships. The method assumes the kinematical model of the own ship and aims to find an optimal balanced trajectory (the balance being between the costs of deviation from a given trajectory and the safety of avoiding static and dynamic obstacles). For a given set of pre-determined trajectories the method finds a safe trajectory, which is optimal according to the fitness function – the optimal safe trajectory. The method's main limitation is that it assumes the target motion parameters not to change and if they do change, the own trajectory has to be recomputed.

The approach proposed here combines some of the advantages of both methods: the low computational time, supporting all domain models and handling stationary obstacles (all typical for evolutionary method), with taking into account the changes of motion parameters (changing strategies of the players involved in a game). Therefore, instead of finding the optimal own trajectory for the unchanged courses and speeds of the targets, a set of optimal cooperating trajectories of all ships is searched for.

The next section presents a formulation of an optimisation problem. Then the structure of an evolutionary population member and its evaluation method are described including a discussion of the constraints and fitness function. Some details on the mechanisms of evolution (including specialised functions and operators) are further provided. Finally the paper summary is presented.

2 OPTIMISATION PROBLEM

It is assumed that we are given the following data:

- stationary constraints (obstacles and other constraints modelled as polygons),
- positions, courses and speeds of all ships involved,
- ship domains,
- times necessary for accepting and executing the proposed manoeuvres.

Obstacles, ship positions and ship motion parameters are provided by ARPA (Automatic Radar Plotting Aid) systems. Ship domain may be determined being given a particular ship motion parameters and length. By default, Coldwell (Coldwell, 1982) domain (an off-centred ellipse) is applied. The necessary time is computed on the basis of navigational decision time and the ship's manoeuvring abilities. By default a 6-minute value is used here.

Knowing these parameters, the goal is to find the set of trajectories, which minimizes the average way loss spent on manoeuvring, while fulfilling the following conditions:

- none of the stationary constraints are violated,
- none of the ship domains are violated,

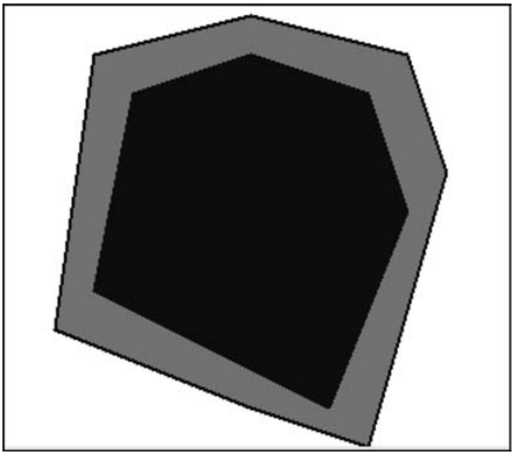

Figure 1. An obstacle (black colour) surrounded by its automatically generated domain (grey colour).

– the minimal acceptable course alteration is not lesser than 15 degrees,
– the maximal acceptable course alteration is not be larger than 60 degrees,
– speed alteration are not be applied unless necessary (collision cannot be avoided by course alteration up to 60 degrees),
– a ship only manoeuvres, when it is obliged to,
– manoeuvres to starboard are favoured over manoeuvres to port board.

The first two conditions are obvious: all obstacles have to be avoided and the ship domain is an area that should not be violated by definition. All the other conditions are either imposed by COLREGS (Cockroft, 1993) (International Regulations for Preventing Collisions at Sea) or by the economics. In particular, the course alterations lesser than 15 degrees are not always detected by the ARPA systems (and therefore may lead to collisions) and the course alterations larger than 60 degrees are highly inefficient. Ships should only manoeuvre when necessary, since each manoeuvre of a ship makes it harder to track its motion parameters for the other ships ARPA systems.

2.1 *Ship domains and obstacle domains*

Each stationary constraint is defined as a polygon given as a sequence of the coordinates of its vertices. Each such polygon is then surrounded by additional domain, whose dimensions are computed by the method. A domain size is specified by the user; by default a 0.25 nautical mile distance is used. An example of an obstacle and its domain is shown in Figure 1.

As for the ship domains, the method supports the following ship domain models:

– a circle-shaped domain (traditional domain shape),
– an off-centred circle (domain shape according to Davis)

Table 1. The dimensions of a circle-shaped domain and Davis domain.

		Domain center moved from the ship's position	
	Domain radius [n.m.]	Towards starboard [n.m.]	Towards bow [n.m.]
A circle	0.5	0	0
Davis domain	0.5	0.1	0.2

Table 2. The dimensions of a Fuji domain and Coldwell domain.

		Domain center moved from the ship's position	
	Ellipse's semi axes [n.m.]	Towards starboard [n.m.]	Towards bow [n.m.]
Fuji Domain	0.77, 0.33	0	0
Coldwell domain	0.77, 0.33	0.1	0.2

Table 3. The dimensions of a hexagonal domain.

Distance towards bow [n.m.]	Distance towards stern [n.m.]	Distance towards starboard [n.m.]	Distance towards port board [n.m.]
1	0.25	0.6	0.25

– an ellipse (domain shape according to Fuji)
– an off-centred ellipse (domain shape according to Coldwell)
– a hexagon (domain shape according to Śmierzchalski)
– a user defined domain (a polygon of user-defined vertices)

The dimensions of those domains are set by the user; the default dimension values are given in Tables 1-3.

3 POPULATION MEMBERS AND THEIR EVALUATION

3.1 *The structure of an individual*

Each individual (a population member) is a set of trajectories (each trajectory corresponding to one of the ships involved in an encounter). A trajectory is a sequence of nodes, each node containing the following data:

– geographical coordinates x and y,
– the speed between the current and the next node.

3.2 *The evaluation of an individual*

The basic piece of data used during the evaluation phase of the evolutionary process is the average way loss computed for each individual (a set of cooperating trajectories). Some of the constraints also must be taken into account during the evaluation. This includes violations of ship domains and violations of stationary constraints: both must be penalized and those penalties – must be reflected in the fitness function. However, as for the other constraints, there are two possible approaches:

1. These constraints can be incorporated in the fitness function.
2. Meeting these constraints can be achieved by applying certain rules on various steps of the evolutionary process simultaneously:
   - when generating the initial population,
   - during mutation,
   - handling the constraints violations by fixing functions operating on individuals prior to their evaluation

The second approach has been chosen here, because of its faster convergence due to:

- its simpler fitness function,
- avoiding the production of individuals (during the mutation phase), whose low fitness function value can be predicted.

Violations of the first two constraints (stationary ones and ship domains) are penalized as follows. For each ship and its set of stationary constraint violations, an obstacle collision factor is computed as given by (4). For each ship and its set of prioritised targets a ship collision factor is computed as given by (3). The reason, why only collisions with prioritised targets are represented in evaluation is because the manoeuvres must be compliant with COLREGS. If a ship is supposed to stay on its course according to the rules, the collision is ignored so as not to encourage an unlawful manoeuvre. In case of collision with prioritised target, the author's measure – approach factor f_{min} (Szlapczynski, 2006b) is used to assess the risk of a crash. Approach factor has been defined as the scale factor of the largest domain-shaped area that is predicted to remain free of other ships throughout the whole encounter situation.

Each individual (a set of trajectories) is being assigned a value of the following fitness function (1):

$$fitness = \sum_{i=1}^{n} [tr\_fit_i], \tag{1}$$

where:

$$tr\_fit_i = \left(\frac{tr\_length_i - way\_loss_i}{tr\_length_i} \right) * sf_i * of_i. \tag{2}$$

sf_i – ship collision factor of the i-th ship computed over all prioritised targets:

$$sf_i = \prod_{j=1, j \neq i}^{n} \left(min(fmin_{i,j}, 1) \right) \tag{3}$$

of_i – obstacle collision factor of the i-th ship computed over all stationary constraints:

$$of_i = \prod_{k=1}^{m} \left(\frac{360° - collision\_course\_range_j}{360°} \right) \tag{4}$$

n – the number of ships [/],
m – the number of stationary constraints [/],
i – the index of the current ship [/],
j – the index of a target ship [/],
k – the index of a stationary constraint [/],
$fmin_{i,j}$ – the approach factor value for an encounter of ships i and j [/],
$collision\_course\_range_j$ – the range of forbidden courses of the ship i computed for the stationary constraint j in the node directly preceding the collision. [/].

To detect the stationary constraint violations of an individual, all of the trajectories are checked against all of the constraints (which are modelled as polygons) and the collision points are found. Analogically, to detect the domain violations of an individual, all of its trajectories are checked against each other to find potential collision points. Unfortunately, applying ship domains instead of safe distances results in higher computational complexity and the process of evaluation consumes the majority of the evolutionary algorithm's computational time. Therefore it has been decided to invest some computational time in specialised functions (validations and fixing) and specialised operators, which speed up the convergence to optimal solution, thus decreasing the number of the generations – and consequently – decreasing the number of evaluations.

4 EVOLUTIONARY PROCESS

4.1 *Generating the initial population*

The initial population contains three types of individuals:

- a set of original ship trajectories – segments joining the start and destination points
- sets of safe trajectories determined by other methods,
- randomly modified versions of the first two types – sets of trajectories with additional nodes, or with some nodes moved from their original geographical positions.

The first type of individuals results in an immediate solution in case of no collisions, or in faster convergence in case of only constraint violations. The second type provides sets of safe (though usually not optimal) trajectories. They are generated by means of two methods: one operating on raster grids (Szlapczynski, 2006a) and the other planning a sequence of necessary manoeuvres (Szlapczynski, 2008). Finally, the third type of individuals (randomly modified individuals of the previous two types) is used to generate the majority of a diverse initial population and thus to ensure the vast searching space.

4.2 *Trajectory validations and fixing*

Representing all of the constraints in the fitness function would result in a very slow progress of the evolutionary algorithm. A good example here is the rule, according to which a course alteration should not be lesser than 15 degrees. Had this constraint been taken into account by the fitness function, slight course alterations, (for example about 5 degrees) would be penalized severely. On the other hand, individuals with no course alterations or with large course alterations would not be penalized. The individuals with no course alterations as well as those with large course alterations would likely be chosen for crossing and would spawn offspring, which again – would probably be penalized for slight course alterations. Therefore some of the constraints are applied as validating and fixing functions. Each trajectory of an individual is analysed and in case of unacceptable manoeuvres (such as slight course alterations), the nodes being responsible are moved so as to round a manoeuvre up or down to an acceptable value.

4.3 *Specialised operators*

The evolutionary operators, which have been used in the current version of the method, can be divided into the following groups.

1 Crossing operators: two types of crossing have been used, both operating on pairs of individuals and used to generate offspring:
  - an offspring inherits whole trajectories from both parents.
  - each of the trajectories of the offspring is a crossing of the appropriate trajectories of the parents.

2 Operators avoiding collisions with prioritised ships: three types of these operators have been used, all operating on single trajectories. If a collision with a prioritised ship has been registered, depending on the circumstances (coordinates of the collision point, way loss, number of target ships and number of nodes within a trajectory) one of the following operators is chosen:
  - node moving: the node closest to the collision point is moved away from it,
  - segment moving: two nodes, which are closest to the collision point are moved away from it,
  - node insertion: a new node is inserted between the two nodes closest to the collision point in such a way that the collision will probably be avoided,

  None of these operations guarantees avoiding the collision with a given target but they are likely to do so and therefore highly effective statistically and suitable for the evolutionary purposes.

3 An operator avoiding collisions with obstacles. a course alteration manoeuvre is made (a new node is inserted) in such a way, that the new trajectory segment does not cross a given edge of an obstacle (polygon).

4 Random operators: three types of these operators have been used, all operating on single trajectories. They are mostly used when a given trajectory does not collide with any prioritised trajectories; otherwise one of the abovementioned collision avoidance operators is more likely to be used. These random operators include:
  - node insertion: a node is inserted randomly into the trajectory,
  - node deletion: a randomly selected node is deleted,
  - nodes joining: two neighbouring nodes are joined, the new node being the middle point of the segment joining them,
  - node mutation: a randomly selected node is moved (its polar coordinates are altered).

A trajectory mutation probability decreases with the increase of the trajectory fitness value (2), so as to mutate the worst trajectories of each individual first, without spoiling its best trajectories. In the early phase of the evolution all random operators: the node insertion, deletion, joining and mutation are equally probable. In the later phase node mutation dominates with its course alteration changes and distance changes decreasing with the number of generations. For node insertion and node mutation instead of Cartesian coordinates x and y, the polar coordinates (course alteration and distance) are mutated in such a way that the new manoeuvres are between 15 and 60 degrees. As a result, fruitless mutations (the ones leaving to invalid trajectories) are avoided for these two operators. Operating on polar coordinates (course and distance) instead of Cartesian x and y coordinates also makes it more likely to escape the local optimums because manoeuvres both valid and largely differing from the past ones are more likely to be generated.

4.4 *Selection*

In the currently developed version of the method the truncation selection has been applied with the truncation threshold of 50%. Although this kind of selection means a loss of diversity, it has the benefit of a fast convergence to a solution. When combined with abovementioned, specialised operators (especially mutation using polar coordinates and operators aiming at collision avoidance), the solution, which the process converges to, is usually the optimal one.

4.5 *Stop condition*

The evolutionary process is stopped if one of the following happens:

- the maximum number of generations is reached,
- the time limit is reached,
- further evolution does not bring significant improvement.

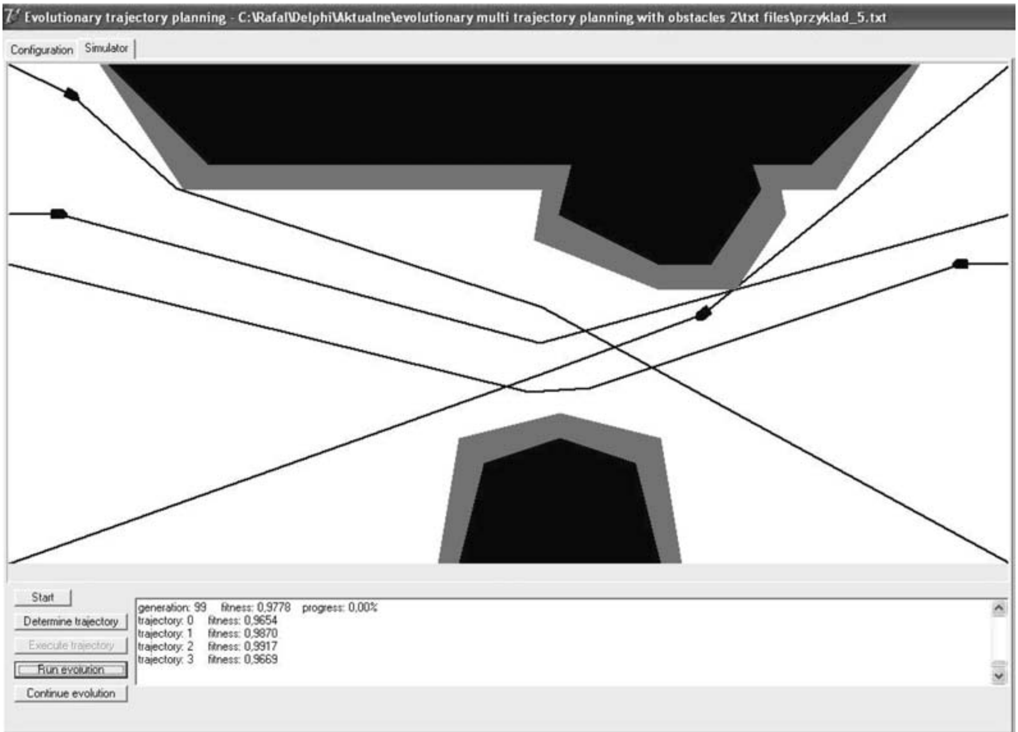

Figure 2. A final set of cooperating evolutionary trajectories with Fuji domain applied.

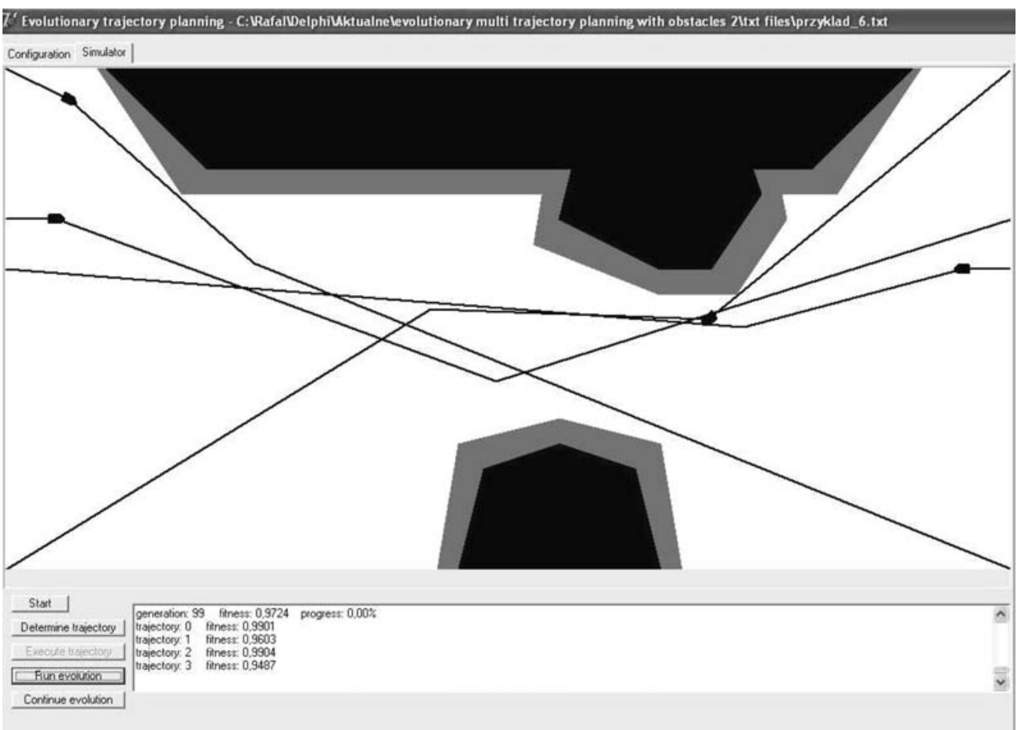

Figure 3. A final set of cooperating evolutionary trajectories with Coldwell domain applied.

5 SIMULATION EXAMPLES

Two examples – simulation results are shown in Figure 2 and Figure 3. In both cases the same scenario has been used, only with different ship domain model applied. Fuji domain has been applied in the situation depicted in Figure 2 and Coldwell domain – in the situation depicted in Figure 3. As a result, slight differences in sizes and shapes of the domains used have caused differences in the trajectories. Most notable one is that the ship starting in the upper right corner of the pictures had to perform an extra manoeuvre to the starboard in Figure 3, to avoid a collision with one of the other ships. The general tendencies of movement of other ships have remained unchanged however. All of the ships chose manoeuvres to starboard, unless course alteration to port board was forced by stationary constraints.

6 SUMMARY

In the paper an evolutionary approach to solving multi-ship encounter situations has been proposed. This approach is a generalization of evolutionary trajectory determining: a set of trajectories of all ships involved, instead of just the own trajectory, is determined. A method implementing this new approach has been developed. The method avoids violating the target ship domains and the given stationary constraints, while minimizing way loss and obeying the COLREGS. It also benefits from a number of author-designed specialized functions and operators, resulting in faster convergence to the optimal solution.

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10.6
Evolutionary sets of cooperating trajectories in multi-ship encounter situations – use cases

R. Szłapczyński
Gdańsk University of Technology, Gdańsk, Poland

ABSTRACT: The paper discusses the advantages of a new approach to solving ship encounter situations by combining some of the assumptions of game theory with evolutionary programming techniques. A multi-ship encounter is here modeled as a game played by "thinking players" – the ships of different and possibly changing strategies. The solution – an optimal set of cooperating (non-colliding) trajectories is then found by means of evolutionary algorithms. The paper contains the results obtained for different cases of situations including open waters and restricted water regions and the discussion of these results. The already developed version of the method is fast enough to be applied in the real time on-board collision avoidance systems or VTS systems.

1 INTRODUCTION

The main approaches to the problem of planning optimal ship trajectories in encounter situations are the methods based on either differential games and evolutionary method. The methods based on differential games were introduced by Lisowski (Lisowski, 2005). They assume that the process of steering a ship in multi-ship encounter situations can be modelled as a differential game, played by all ships involved, each having their strategies.

The second approach – the evolutionary method of finding the trajectory of the own ship has been developed by Śmierzchalski (Śmierzchalski, 1998). For a given set of pre-determined trajectories the method finds a safe trajectory, which is optimal according to the fitness function – the optimal safe trajectory. The method's main limitation is that it assumes the target motion parameters not to change and if they do change, the own trajectory has to be recomputed.

The approach proposed here combines some of the advantages of both methods: the low computational time, supporting all domain models and handling stationary obstacles (all typical for evolutionary method), with taking into account the changes of motion parameters (changing strategies of the players involved in a game). Therefore, instead of finding the optimal own trajectory for the unchanged courses and speeds of the targets, a set of optimal cooperating trajectories of all ships is searched for. The early version of this method has already been described by the author in (Szlapczynski, in press). The method had been successfully implemented and tested and the paper presents some representative simulation results covering different use cases.

The rest of the paper is organized as follows. Section 2 contains simulation parameters and is followed by several types of scenarios, where the proposed method is able to predict the behaviour of targets and plan own collision avoidance manoeuvre in advance, even though sometimes there is seemingly no need to perform a manoeuvre at the moment. These scenarios include the following situations: a target changing its course because of landmass (Section 3), a prioritised target changing its course because of another target (Section 4) and finally multi-ship encounters with all ships manoeuvring to avoid collisions on open waters (Section 5) and restricted area (Section 6). The last section contains the paper's summary and conclusions.

Table 1. The dimensions of Coldwell domain used in the simulation scenarios.

		Domain centre moved from the ship's position	
	Ellipse's semi axes [n.m.]	Towards starboard [n.m.]	Towards bow [n.m.]
Coldwell domain	0.77 0.33	0.1	0.2

2 SIMULATION PARAMETERS

In the scenarios below each stationary constraint is surrounded by a domain of the size specified by the user; the default safe distance of 0.25 nautical mile has been used. As for ship domains – a Coldwell domain (Coldwell, 1982) has been assumed for all ships. Its default dimensions (used in all scenarios) are given in Table 1.

The evolutionary parameters values are listed in Table 2.

Table 2. The evolutionary parameters values used in the simulation scenarios.

Number of generations	100
Population size	100
Selection method	Truncation selection with the truncation threshold of 50%
Mutation probability (for a single trajectory)	Depends on the trajectory fitness value (from 0% for perfect trajectories to 100% for unacceptable ones)

Table 3. The motion parameters of both ships.

	Speed [knots]	Course [degrees]	Position coordinates at the start time [n.m.]		Coordinates of the destination point [n.m.]	
			x	y	x	y
Own ship	12	90	0	2	10	2
Target 1	12	270	10	3	0	3

Figure 1. The own ship's current course does not collide with the landmass (black) or its domain (grey).

3 SCENARIO 1: A TARGET MANOEUVRING TO AVOID COLLISION WITH LANDMASS

The positions, destination points and speeds of the ships are given in Table 3.

The current course of the own ship does not collide with neither the landmass (Figure 1) nor the target ship (Figure 2).

However, the target's course collides with the landmass and the target will perform a collision avoidance manoeuvre (Figure 3).

The method predicts the target's manoeuvre and plans the own ship's manoeuvre in advance. The final evolutionary set of two cooperating trajectories of both ships is shown in Figure 4.

Figure 2. The own ship (left) course does not collide with the current course of the target (right). Landmass is not shown.

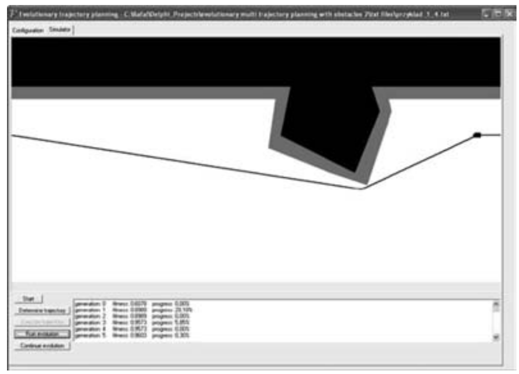

Figure 3. The target's current course collides with the landmass so the target will perform a collision avoidance manoeuvre.

4 SCENARIO 2: A TARGET MANOEUVRING TO AVOID COLLISION WITH ANOTHER TARGET

The positions, destination points and speeds of the ships are given in Table 4.

The current course of the own ship does not collide with neither of the two prioritised ships. The safe trajectories for encounters with either target 1 only or target 2 only are shown in Figure 5 and Figure 6 respectively. As can be seen – no manoeuvres are needed.

However, the first target's course collides with target 2 and the target 2 is a "stand-on vessel" according to COLREGS (Cockcroft, 1993). As a result, the first target will perform a collision avoidance manoeuvre (Figure 7).

The method predicts the manoeuvre of target 2 and plans the own ship's manoeuvre in advance. The final evolutionary set of three cooperating trajectories is shown in Figure 8.

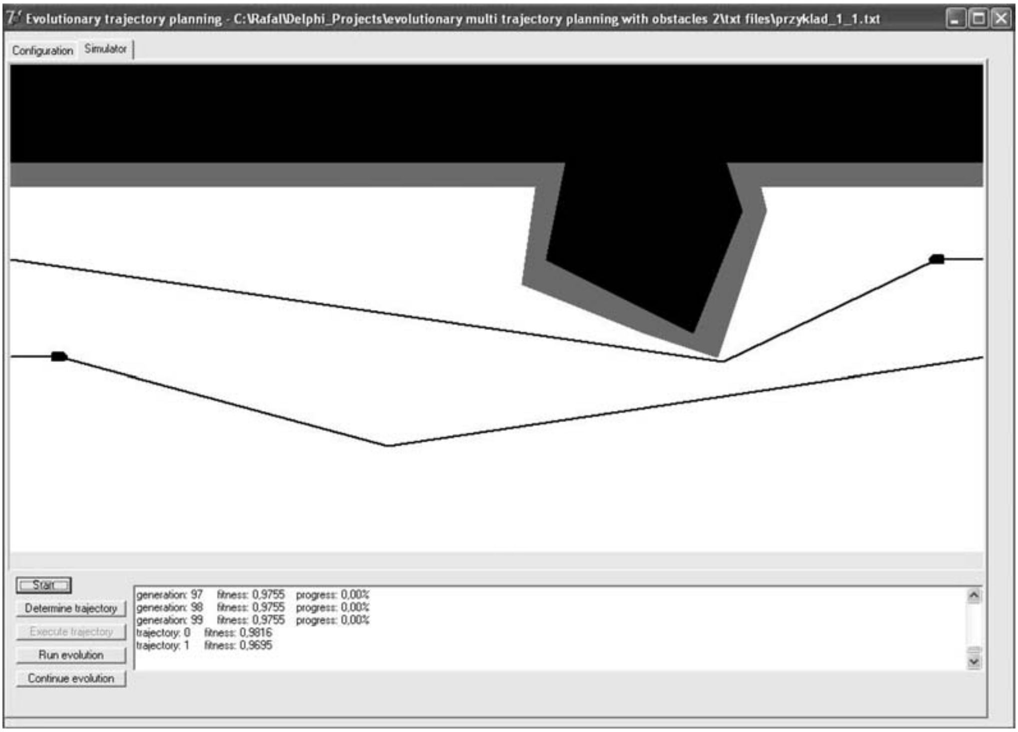

Figure 4. The evolutionary set of the two ships' cooperating trajectories, which avoid collisions with the landmass and each other.

Table 4. The motion parameters of all ships.

	Speed [knots]	Course [degrees]	Position coordinates at the start time [n.m.]		Coordinates of the destination point [n.m.]	
			x	y	x	y
Own ship	12	45	0	0	10	5
Target 1	8	0	5	0	5	5
Target 2	17	270	10	2.5	0	2.5

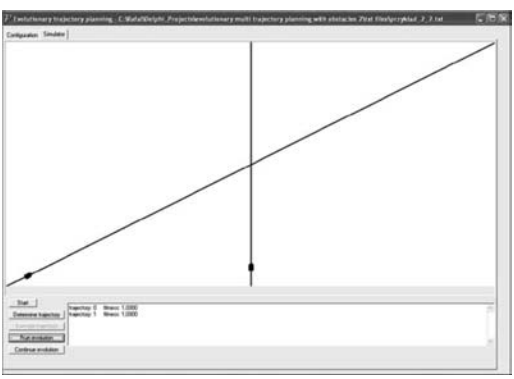

Figure 5. The own ship's current course (left) does not collide with target 1 (right).

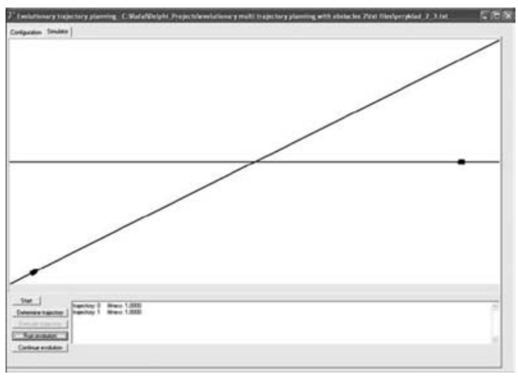

Figure 6. The own ship's current course (left) does not collide with target 2 (right).

5 SCENARIO 3: A GROUP OF SHIPS MANOEUVRING TO AVOID COLLISIONS WITH EACH OTHER ON OPEN WATERS

The positions, destination points and speeds of the ships are given in Table 5.

The current courses of the ships are such that all of the ships would collide in the central point of the area. The final evolutionary set of the safe cooperating trajectories, which avoid collisions with each other, is shown in Figure 9.

6 SCENARIO 4: A GROUP OF SHIPS MANOEUVRING TO AVOID COLLISIONS WITH EACH OTHER AND OBSTACLES

The positions, destination points and speeds of the ships are given in Table 6.

The current courses of all four ships collide with each other or the landmass. The final evolutionary set of four cooperating safe trajectories is shown in Figure 10.

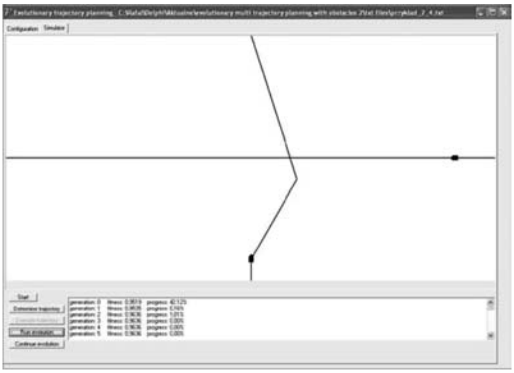

Figure 7. The first target's current course (left) collides with target 2 (right) and target 1 performs collision avoidance manoeuvre.

Table 5. The motion parameters of all ships.

	Speed [knots]	Course [degrees]	Position coordinates at the start time [n.m.]		Coordinates of the destination point [n.m.]	
			x	y	x	y
Ship 1	5	0	5	0	5	5
Ship 2	14	45	0	0	10	10
Ship 3	10	90	0	2.5	10	2.5
Ship 4	14	135	0	5	10	0
Ship 5	5	180	5	5	5	0
Ship 6	14	225	10	5	0	0
Ship 7	10	270	10	2.5	0	2.5
Ship 8	14	315	0	10	0	5

Table 6. The motion parameters of all ships.

	Speed [knots]	Course [degrees]	Position coordinates at the start time [n.m.]		Coordinates of the destination point [n.m.]	
			x	y	x	y
Ship 3	10	90	0	2.5	10	2.5
Ship 4	14	135	0	5	10	0
Ship 6	14	225	10	5	0	0
Ship 7	10	270	10	3	0	3

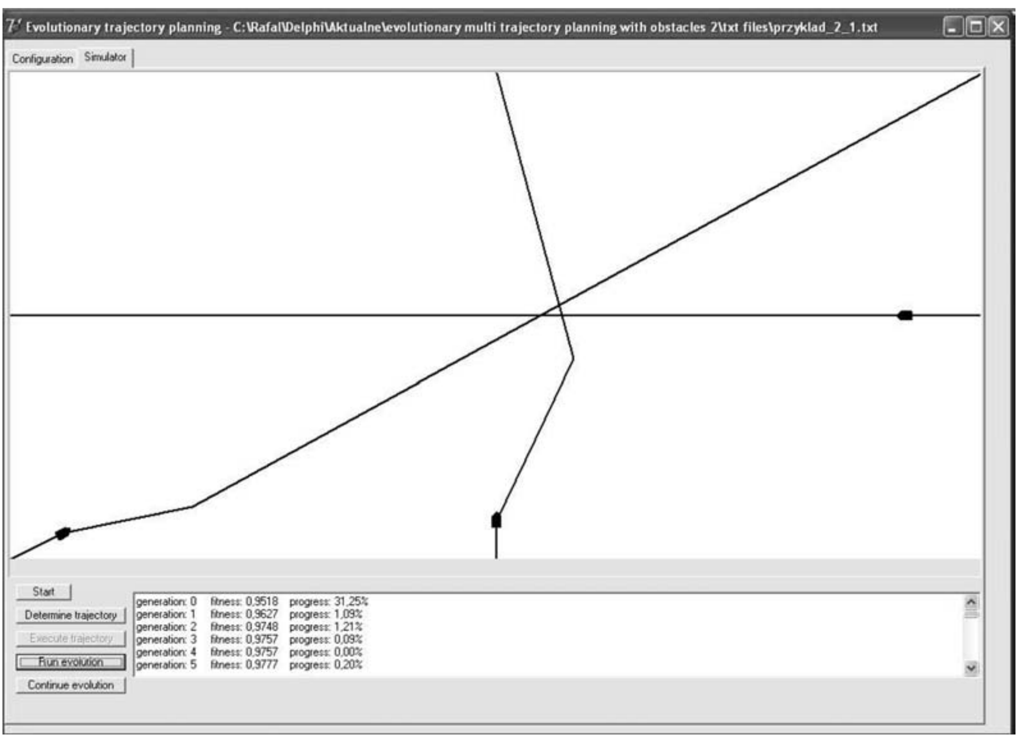

Figure 8. The evolutionary set of the three ships cooperating trajectories, which avoid collisions with each other.

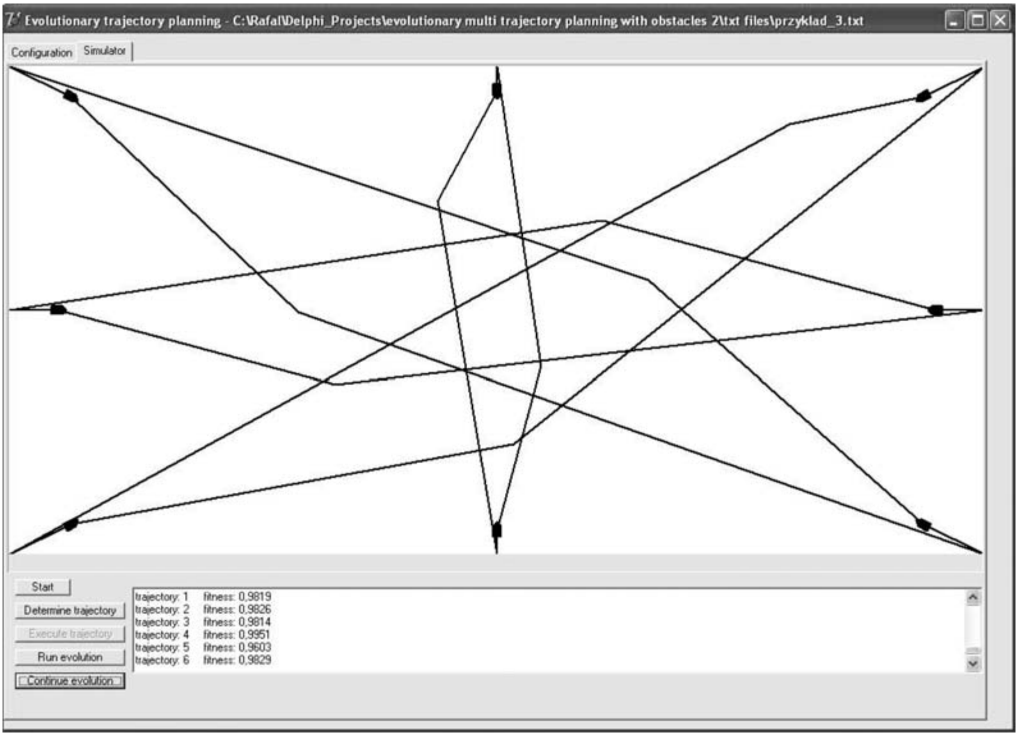

Figure 9. The evolutionary set of the eight ships' cooperating trajectories, which avoid collisions with each other.

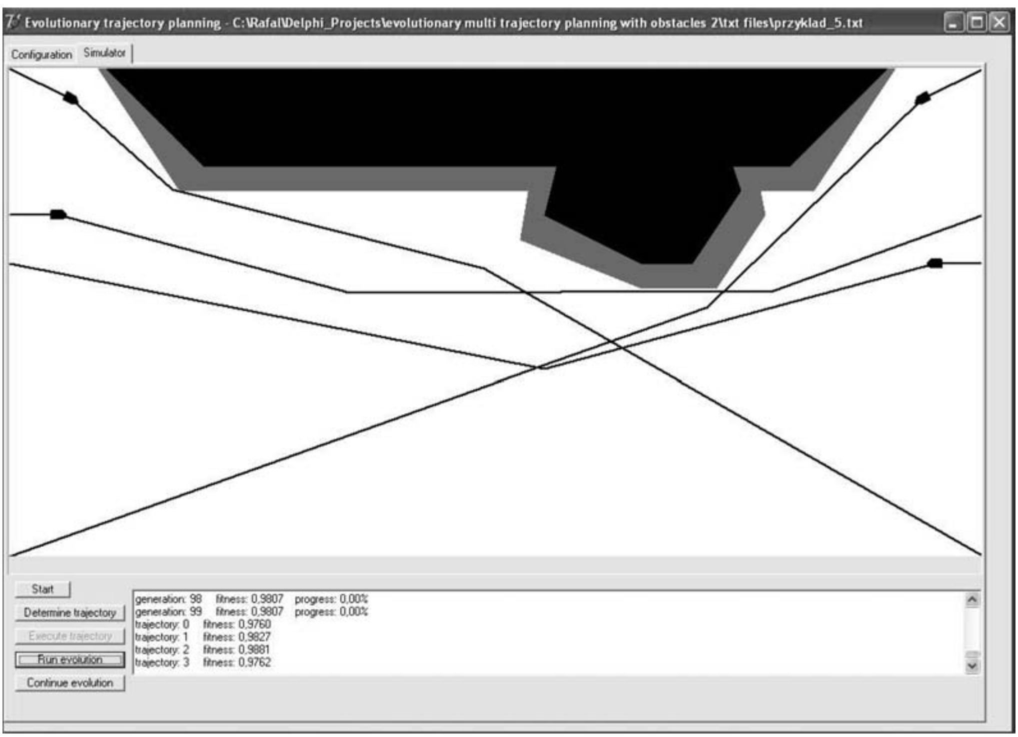

Figure 10. The evolutionary set of the four ships' cooperating trajectories, which avoid collisions with each other and the landmass (landmass in black, landmass domain in grey).

7 SUMMARY AND CONCLUSIONS

In the paper some examples of use of evolutionary approach to solving ship encounter situations have been proposed. This approach is a generalization of evolutionary trajectory determining: a set of trajectories of all ships involved, instead of just the own trajectory, is determined. The method avoids violating the target ship domains and the given stationary constraints, while minimizing way loss and obeying the COLREGS. As has been shown in case of simple scenarios (where ship priorities are clearly described by COLREGS), the method is able to predict the probable manoeuvre of a target and plan own ship manoeuvre in advance. Because of its low computational time the method can be applied to both on-board collision-avoidance systems and VTS systems. In the former it could be used for solving simple scenarios and assessment of more complex ones, in the latter it could successfully solve any given scenario involving multiple ships and stationary constraints.

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Chapter 11. Hydrometeorological aspects

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)
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11.1 Contemporary problems of navigation nearly pole

E.M. Lushnikov
Maritime Academy, Szczecin, Poland

ABSTRACT: The problem of navigation at geographical poles is considered. Means and methods of its realization are offered within the framework of classical navigation. Brings an attention to the question on production of pseudomercator's navigational charts.

1 INTRODUCTION

The Arctic Ocean represents an enormous reserve of mankind for the most various aspects.

At first the Arctic Ocean is extremely favourable sea way through all east hemisphere.

At second the Arctic Ocean is an enormous source of natural resources, which use else begins.

The most active in part of development of Arctic regions demonstrates Russia. The activity of Russia in Arctic Ocean speaks parameters of load transportation by Northern sea way. Russia is the unique country in the world which has the nuclear ice-breaking fleet of ten units.

2 NUCLEARS ICE-BREAKERS FLEET OF RUSSIA

First nuclear ice-breaker "*Lenin*" has been constructed at the Admiralty factory in 1959 years. The next nuclear ice-breakers should be were building at the Baltic factory of Saint Petersburg. The nuclear ice-breakers "*Tajmyr*" and "*Vaigach*" have been constructed in Finland, and a nuclear stuffing was installed at the Baltic factory of Saint-Petersburg.

At time of industrial depression in Russia the nuclear ice-breaking fleet has been compelled to search for sources of financing. For this purpose nuclear ice-breakers twenty years make tourist flights to North Pole.

Ice-breakers of a class "*Arctic*" make a basis of the Russian nuclear ice-breaking fleet. Six ice breakers from 10 concern to this class. This series of a vessels was under construction during 30 years, therefore the last of vessels have essential differences. The vessels of this type have characteristics:

– Length – 150 m. – cancel fullstop (136 on a waterline);
– Width – 30 m (28 on a waterline);
– The draft – 11,08 m.;
– The height – 55 m. – cancel fullstop (from keel) up to top of mast;
– The maximal speed – 23,8 knots;
– Crew – 150 person
– Passengers – 100 person (in 50 cabins)
– Power installation – two reactors OK-900 capacity on 171 MW every.

These ice-breakers have the double body. Thickness of the external body in places ice contact is 48 mm, and in other places 25 mm.

At normal operating mode it is enough one of two reactors, but during navigation are involved both (at less than 50% of capacity).

3 EXPANSION TO NORTH POLE OF RUSSIA AND OTHER COUNTRY

From 1989г. nuclear ice-breakers go to North Pole with tourists. Cost of cruise makes about 25000 $.

Ice breaker "Yamal" (see fig. 1) in july – august specializes on tourism, having made already more than 50 campaigns to a pole.

In 1998 years the nuclear ice-breaker "Arctic" for the first time has carried out nearly pole ice posting of German scientifically research ice breaker "*Polarstern*". At 2004 years the ice-breaker "Soviet Union" together with Swedish diesel ice breaker "*Oden*" provided ice safety of chisel works on North Pole from a vessel "*Vidar Viking*".

Recently Russia and the USA have submitted for consideration the United Nations a question on expansion of the shelf territories in area of Arctic ocean.

For a substantiation of the claims Russia has made researches in area of North Pole. It was immersed on a bottom the deep-water device in a point of North Pole. It was established at the bottom a memorable sign of Russia from the titan.

Claims of a similar sort on expansion of territories of shelf zones are possible as on the part of Canada, Iceland, Denmark and Norway. Similar claims

Figure 1. Nuclear ice-breaker *"Jamal"*.

is explained by presence in the Arctic zone of the big stocks of oil and gas.

Already practical development of Arctic ocean by Russia in area of Shtokman oil field begins. All this will inevitably lead to wider use of the Arctic water areas for navigation and economic activities.

4 THE PROBLEMS OF EXOTICAL NAVIGATION TO NORTH POLE

The navigation nearly of geographical poles has a general difference to traditional navigation.

For the poles it is lose sense such major classical concepts of navigation, as a meridian of observer, a parallel of observer, a course of vessel, a bearing of subject, rhumb line bearing, great circle bearing.

For single (exotic) expeditions there is long prepare, all beforehand is thought over and rehearsed, involved scientific forces and means.

In conditions of mass actions (development of sea and bottom's resources) there is a question on the maximal simplification of process of navigation in these areas. It is necessary to make a navigation in the maximal degree similar to conditions of usual navigation with use of standard means and methods.

The greatest convenience for plotting gives the map of Mercator projection. This projection is equiangular. The line of a constant course – rhumb line is represented on a map by a direct line. This circumstance does a work of plotting of a way extremely simple and convenient.

The main lack of such projection is so, that with change of geographical latitude the scale of a map changes proportionally to sec φ, in this connection, in latitude more 85° use of mercator projections is inexpedient basically.

Difficulties of the Arctic navigation are not limited to problems of use habitual mercator maps.

In these latitude there is practically unsuitable a gyrocompass. On a pole, a gyrocompass we shall fail basically, and the concept of a course degenerates owing to absence of a meridian of the observer.

At navigation nearly magnetic poles which are located far enough from geographical poles for navigation there is completely not suitable a magnetic compass. The directing moment of a magnetic compass on a magnetic pole is equal to zero. From this reason a magnetic compass is disabled. Here it is necessary to notice, that by definition the magnetic compass is a device for the indication of a magnetic meridian. However in a point of a magnetic pole all magnetic meridians is crossed. The concept for meridian of observer from this reason is degenerates.

The position of northern magnetic pole for 1st January of 2005 year is situated at $\varphi = 82^0 07' N$, $\lambda = 114^0 04' W$. The coordinates of a southern magnetic pole for 1st january of 2004 year is $\varphi = 63^0 05' S$, $\lambda = 138^0 00' E$.

Nearly of magnetic poles the gyrocompass has a admissible accuracy, and the map of Mercator quite provides a requirements of navigation.

Apparently, usual navigation will be completely paralysed only at geographical poles.

Classical navigation near to geographical poles it is possible to provide by magnetic compass and pseudomercator's map. Pseudomercator's map differs from mercator's map by the way of construction.

The axis of Mercator's cylinder passes through the centre of the Earth and geographical poles. The axis pseudomercator's cylinder passes through the centre of the ground and a corresponding magnetic pole of the ground (northern or southern).

Thus, the angle between axes of Mercator's and pseudomercator's cylinder is equal to the polar distance Δ measured from a geographical pole up to the corresponding magnetic pole (fig. 2).

The turn of the projective cylinder at pseudomercator's projection leads to respective alterations of the habitual image of a ground surface which was observed at mercator's map. These changes, however, do not render a special influence on perception of a map through navigator, so as habitual mercator's projection also deforms the form of terrestrial objects and the more strongly, than they are closer to poles.

The polar cap at a geographical pole from a parallel 85° and above excludes use of Mercator maps and a gyrocompass.

At the pseudomercator's projections this polar cap is situated outside the new restrictive circle.

It will allow at navigation near to geographical poles to use a pseudomercator's map in aggregate with a magnetic compass and to continue navigation as usual.

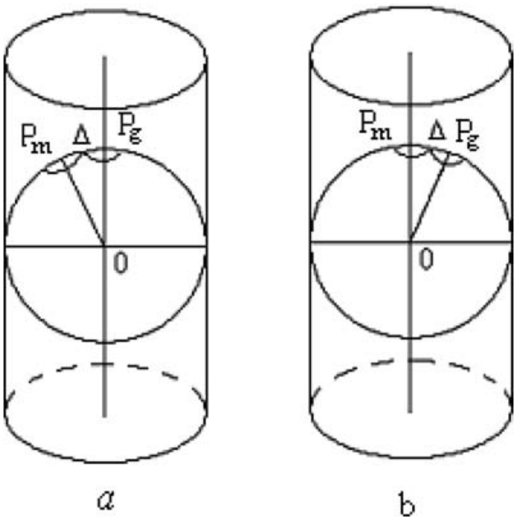

Figure 2. The projection cylinder for Mercator's and Pseudomercator's maps a – Mercator's projection, b – Pseudomercator's.

Table 1. Means of classical navigation at navigation in subpolar areas.

Kind of water area	
Near to a magnetic pole	Near to a geographical pole
1. Navigating Mercator's chart 2. Gyro compass	1. Navigating pseudomercator's chart 2. Magnetic compass

Thus, means allowing to carry out classical navigation at subpolar areas look how it is shown in table 1.

Realization of classical navigation near to geographical poles demands new type of a map, namely, maps in pseudomercator's projection.

The grid of such pseudomercator's projections by the form will differ nothing from a grid of mercator's projections, but coordinates of all points of a surface of the ground should be in appropriate way counted.

The coordinates of magnetic poles on surface of earth changes position. For example, the point of northern magnetic pole recently will annually get mixed up on a terrestrial surface approximately 40 km. In this connection, it is required to trace periodically these changes and to bring corresponding corrections for recalculation of a map's grid. For electronic maps this procedure does not represent any complexities.

Here it is necessary to notice, that magnetic poles are located far from being in opposite points of the Earth. This circumstance compels to make a grid of pseudomercators map for northern geographical pole and southern pole in separate execution.

The role of a true meridian at pseudomercator's map will be carried out a line directed on magnetic pole. As well as in mercator's map, vertical lines of a cartographical grid are considered as true meridians from which true courses and bearings are considered.

A sizes of variations V for pseudomercator's map should be rendered in view of a changed coordinate grid. The formula for finding of the amendment to recalculation of variation ΔV enters the name as:

$$\Delta V = arcctg\left(ctg\Delta \cdot \cos\varphi \cdot \cos ec\Delta\lambda - \sin\varphi \cdot ctg\Delta\lambda\right)$$

where:

Δ – polar distance of a magnetic pole;
φ – geographical latitude of the ship;
$\Delta\lambda$ – the difference of geographical longitudes of a magnetic pole and the ship.

5 CONCLUSION

Unification of plotting at use of pseudemercator's maps allows to avoid navigating discomfort at navigation in areas of geographical poles, to remove unnecessary stressful situations and by that to raise safety of navigation.

LITERATURE

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http://www.luxe.ru

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

11.2
A case study from an emergency operation in the Arctic Seas

B. Kvamstad, K.E. Fjørtoft & F. Bekkadal
MARINTEK e-Maritime, Trondheim, Norway

A.V. Marchenko
The University Centre in Svalbard, Norway

J.L. Ervik
The Norwegian Coastal Administration, Oslo, Norway

ABSTRACT: The objective of this paper is to highlight the needs for improved access to high quality maritime data and information in the Arctic, and the need to develop maritime communication infrastructure with at least the same quality, in terms of availability and integrity, as in other more centralized areas. The foreseen Arctic ice meltdown is expected to provide new maritime transport corridors within relatively short time, and there is an urgent need to prepare for this, to ensure safe operations at sea and to protect the vulnerable Arctic environment.

This paper points out some of these needs by presenting a case from a former accident in the Arctic sea. The case shows how the lack of proper information and data complicates the emergency operation. Some possible solutions to the challenges are proposed, and finally the paper briefly discusses the IMO e-Navigation concept in light of the Arctic challenges.

1 INTRODUCTION

Emergency operations are always critical, regardless of the position on earth. The need for high quality data at the right time is essential, and the need is crucial in all phases of an emergency operation. In some places on earth it is, however, more difficult to manage emergency operations due to harsh environments and long distances, lack of suitable communication means and poorly developed search and rescue (SAR) facilities and services, which is most definitely the case for Arctic areas.

It is foreseen that within this century the Northeast and Northwest passages may well become alternative transport corridors between the Eastern and Western parts of the world, and that the maritime traffic will increase significantly in these areas (Orheim, 2008). A consequence of this will most certainly be an increased number of accidents that could have fatal impact on people and the vulnerable Arctic environments. Also, new requirements to meet the navigational challenges will appear, such as e.g. requirements for real-time meteorological data updates and prognoses to be used in the planning of a voyage.

To illustrate some of the challenges pertaining to emergency operations in the Arctic waters, a case from an earlier accident is described. The focus is on the availability of information, data and communication means, and it includes all elements in an emergency operation (emergency team, SAR vessel, ship in distress, passengers, operation centre ashore etc.).

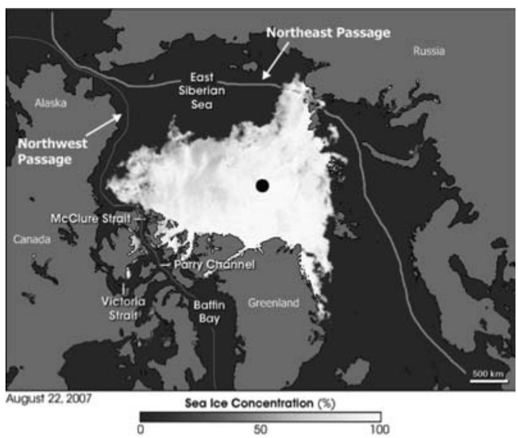

Figure 1. The Northeast and Northwest passages.

1.1 *MS Maxim Gorkij*

At 00.40 on the 17th of September 1989, the Captain on board the Norwegian Coast Guard vessel KV Senja received a message from Svalbard radio that a vessel positioned 60 nm West of Isfjorden required assistance. The ship in distress was a Russian vessel chartered by a German tour operator; having 953 people on board, whereof 575 passengers and 378 crew members. It was on its way to the Magdalena fjord at Svalbard when the crew discovered ice and took the vessel closer to it to show the passengers. The weather

Figure 2. MS Maxim Gorkij passengers.
Photo: Odd Mydland.

Figure 3. MS Maxim Gorkij passengers in lifeboat.
Photo: Odd Mydland.

conditions were good, a bit hazy, but no wind and only 2–3 m swell. At 23.05 Maxim Gorkij collided with the ice. A crucial maneuver resulted in a 10 m long rip in the hull in addition to some smaller rips in the bow. At 00.05 Maxim Gorkij's Captain sent an emergency message on the distress frequency 500 kHz requesting assistance.

When KV Senja received the message from Svalbard radio the vessel finished it's inspections in the area around Isfjord radio and went by 22 knots to the position of Maxim Gorkij. Estimated time of arrival was 04.00, 5 hours after the time of the accident. KV Senja did not have any information on what had happened, what type vessel or the extent of the emergency. The only available information was that a vessel was in distress and the position of this vessel.

At 01.00 KV Senja received a message via a poor VHF link from Maxim Gorkij that the vessel took in water, but remained stable. At 01.30 KV Senja received a message that passengers and crew went into the lifeboats. On basis of this information the crew on KV Senja started to plan the rescue operation. The resources they had on board were 53 people, a medical treatment capacity of 110 persons, medical personnel, divers and various equipments such as cranes and smaller boats. However, when they arrived at the scene of the accident, almost nothing was possible to perform as planned, since:

- A 1.5 nautical mile (nm) deep ice-belt of about 1m thickness was separating KV Senja from Maxim Gorkij.
- The cultural and language differences between Russian and Norwegian crew made communication difficult, including the communication with the Master on board the Maxim Gorkij.
- The passengers were mostly elderly people that needed rapid and extra assistance to get out of the lifeboats and on board KV Senja.

Another complicating issue was that the requested rescue helicopters had to refuel in the air, and they had to land on KV Senja with passengers, even though the helicopters were too large to be using the ship as landing place.

At the bridge of KV Senja some of the main challenges were to accommodate requests from the press and worried relatives, coping with poor support from decision makers on the mainland and few available resources.

After some critical moments and huge efforts from the emergency team, KV Senja could finally leave for Longyearbyen (at Svalbard) with the crew and passengers from Maxim Gorkij. The Russians were able to save their ship with assistance from KV Senja's divers. Luckily no one died or was seriously injured. There were only a few minor injuries among the emergency team.

The Maxim Gorkij incident is not the only of its kind. A more recent accident happened to the MS Explorer, which was tragically lost in 2007. Although taking place in Antarctica, the scenario was generally the same: The vessel collided with ice, rescue assistance was far away, the vessel MS Nord Norge just by coincidence happened to be in the area and were able to assist MS Explorer.

Also, in 2008 there were 4 ship incidents in the waters near Svalbard, and in January 2009 there were two accidents with fishing vessels in this area, where the Captain on board one of them tragically lost his life. (Svalbardposten, 2009a) (Svalbardposten, 2009b).

2 CHALLENGES

The case study of Maxim Gorkij reveals several deficiencies in information availability, both for the planning- and the execution phases of the rescue operation. In the following sections the main challenges are identified and categorized to information and data, and communications.

2.1 *Information and data*

In the planning phase, which started at the moment KV Senja received a message from Svalbard radio that a vessel needed assistance at 60 nm West of Isfjorden, the lack of information and data is striking. The only information available was: A vessel was in distress at this position, making it virtually impossible to plan the rescue operation. Information that should have been available at KV Senja was:

– What type of vessel was in distress? Was it a smaller fishing vessel with but a few persons on board, was it a tanker that could leak oil or was it a cruise ship with lots of crew and passengers?
– How was the weather and ice conditions? Was the vessel trapped in ice? Was it windy? Difficult waves?
– Were other vessels in the area that could possibly assist?

On the way to the emergency scene, two messages were received from Maxim Gorkij, via a poor VHF channel. One of the messages contained information that the vessel was stable, and the next informed that passengers were transferred to the lifeboats. A question to be raised is whether Maxim Gorkij had tried to contact other vessels at an earlier time, but was not able to reach anyone due to the poor communication link?

The initial operation phase started when KV Senja finally arrived at the emergency scene. The rescuers recognised that almost nothing of the initial planning could be used; they were not prepared at all on the real situation. The first surprise was the ice belt, the second was the condition of the passengers having left the lifeboats and stood on ice floes, waiting to be rescued. They were mostly elderly people, in their nightwear and coats. The new goal of the rescuers on KV Senja was therefore immediately changed to: 'Rescue as many people as possible'. It is easy to imagine what benefit better access to information could have added to the emergency operation:

– An overview of the emergency scene in terms of ice and weather conditions would assist them in planning an alternative route to the emergency scene.
– By getting information on the type of vessel, number of passengers and the condition of the passengers they could have prepared for a reception adjusted to this information.

In the next stage of the operation phase, one of the challenges was the lack of information and support from operation centres and decision makers ashore. One example is the use of helicopters. The helicopters were, according to laws and regulations, too large to land on KV Senja. However, if they did not land the helicopters, they would use more time to rescue the passengers. Having in mind that they were out there in relatively thin clothing in harsh environments, the rescuers had to make fast decisions. The decision and responsibility on overruling the laws and regulations was put on the shoulders of the Captain on board KV Senja and the helicopter pilot. If they had had online contact with an operation centre ashore, which again had continuously contact with necessary decision makers, they could have received a temporary allowance to perform the operation. In such way they would not have had to waste time worrying about the personal consequences of breaking the rules. Luckily the Captain and the helicopter pilot were willing to take personal risks to save the lives of the Maxim Gorkij passengers. What if they had not?

Another issue, which probably had to do with cultural differences in addition to lack of information, was the Russian helicopters that suddenly appeared at the emergency scene, dropping packages on the deck of Maxim Gorkij. The people on board the KV Senja had no information on how many Russian helicopters to expect or what they were doing. An operation centre ashore could most probably have assisted in finding out what they were doing by making contact with Russian colleagues, and then providing KV Senja with this information.

2.2 *Communications*

The relation between getting access to high quality data and information and the availability of communication channels is obvious. Without a proper communication link it is impossible to distribute the information. Different potential communication technology solutions are discussed in the next section. The communication challenges pertaining to the Maxim Gorkij accident were:

– Limited or almost no possibilities to communicate with the vessel in distress.
– No on-line communication link between an operation centre and the emergency operation team (KV Senja and the helicopters).
– No communication link for weather and ice updates, and other information to enhance situational awareness.
– The communication link (Isfjord radio) was also occupied by worried relatives and the press

Even if the Maxim Gorkij accident happened 20 years ago, the above challenges regarding communication infrastructure and access to high quality data and information has remained almost unchanged in the Arctic areas. This accident ended without loss of lives and hazardous consequences for the environment thanks to dedicated rescuers and nice weather conditions. The question to be raised is: What will happen when the traffic increases and hence the emergency rate increases? Are we willing to take a chance on the weather conditions and rescuers that are in the area by coincidence? There is an immediate need to address the issues of communications, information and data, and in the following sections possible solutions are proposed and assessed.

3 POSSIBLE SOLUTIONS

3.1 *Information and data*

On basis of the challenges described in the above sections the following information and data is considered useful and necessary during an emergency operation:

- Meteorological- and hydrological ocean data (weather-, wave- and ice data)
- Information to increase situational awareness (type of ship, number of passengers, condition of passengers, condition of ship, surrounding traffic)
- Improved Electronic Navigation Charts (ENC's)
- Improved emergency preparedness tools
- Status on and from fairway objects (lighthouses, buoys, sensors to monitor stream, temperature, wind, etc.)

Some of this information and data sources are further described in the following sub-sections.

3.1.1 *Meteorological- and hydrological ocean data*

Today several maritime services are broadcasting information on weather and sea conditions via radio channels and on the Internet. To offer such services in the Arctic areas, sufficient observation and measurement sites are required, along with an adequate communication link for data distribution. This challenge is due to the long distances over open sea and harsh weather conditions. Another challenge is the information on ice conditions. The solutions available for such information are presently satellite images from Synthetic Aperture Radars (SAR) and near ship ice monitoring by the use of cameras on the bow of ice breakers. Investigations have been and are being conducted to test out how the satellite images can be used by vessels sailing through icecovered waters. One of the challenges is to understand and read the images without having enough knowledge or experience of reading ice surfaces from satellite pictures.

This type of information can be particularly useful for voyage planning. By using this type of data the planners are able to set up routes outside ice-covered waters, or possibly through openings in the ice. However, these satellite images can not be used for real-time monitoring of ice conditions near the ship. It can not provide any information on rapid changes in ice conditions and thickness.

A study performed at the University Centre in Svalbard (Marchenko, 2009) shows that it is possible, by advanced techniques, to calculate velocities on ice, ice compactness and the effect on ships sailing in this ice – compactness meaning the concentration of ice on the sea surface. For example, if half of sea surface is covered by ice and another half is ice-free, the compactness is equal to 0.5. These calculated parameters can be used to show ice compactness on maps, and it is one of parameters characterizing ice structure in numerous numerical models of sea ice coverage dynamics. The conclusions from the study are:

1. Spatial evolution velocities of compacted ice regions depend on the compactness of surrounding rare ice, with typical values reaching a few meters per second when rare ice compactness is larger than 0.6.

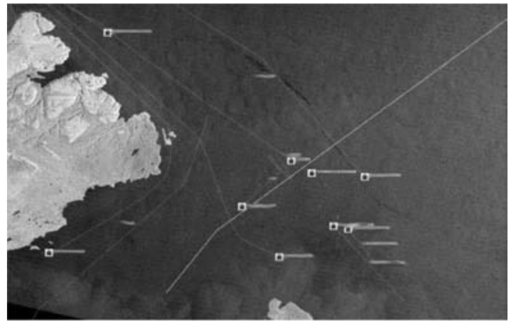

Figure 4. Combination of satellite images and AIS data. Photo: Kongsberg Satellite Services (KSAT).

2. The ship resistance caused by rare ice can be in the order of the water resistance when rare ice compactness is larger than 0.5 and floe diameters are about the ship width.
3. When ice compactness is close to the critical value of 0.78, the performance of small ships with maximum speed of about 10 knots in open waters, is very poor. Practically they will be captured by the ice in this case.

By combining and using these parameters it could be possible to develop an advanced and accurate real-time decision tool for voyages in ice-covered waters infested. This could also be used in an emergency operation as a decision support tool. In the Maxim Gorkij case, such tools could have been used to assist the Captain onboard KV Senja to decide whether or not to move trough the ice belt.

3.1.2 *Situational awareness*

Information that would increase the situational awareness both in the planning- and execution phase of an emergency operation, is information pertaining to the ship in distress. Examples of such information are vessel type, size, condition of vessel, number of passengers, condition of passengers, information on surrounding traffic and available resources.

One possible solution to this is to combine data from several sources, e.g. images from surveillance satellites and ship information from AIS or LRIT, as exemplified by the picture in Figure 3. The Norwegian Coastal Administration has utilized satellite images from surveillance satellites to detect oil spills in Norwegian waters. From these satellite images it is impossible to see which ship is responsible for this. However, if a layer of AIS data is put on top of the images, the ship can be identified. In areas beyond coverage from land-based AIS base stations, future space-based AIS or other sources can be used to identify the ship, e.g. the evolving LRIT system.

This way of combining data could also be used for surveillance of emergency operations. Today the time delay of data from satellite is to large, but future developments of the communication infrastructure might solve that problem.

3.1.3 *ENC's and preparedness tools*

The existing Electronic Navigation Charts (ENC's) for the Arctic seas are far from mature, since it has been difficult to develop these charts due to the ice covering sea and land. This work needs to be started as soon as the landscape is visible. Satisfactory charts represent a crucial factor to increase the safety of navigation.

Preparedness tools are also something that need to be developed. In Norway work is ongoing to develop such tools and also work is started to investigate possible areas to be used as port of refuge.

3.2 *Maritime communication technologies*

The previous sections clearly illustrate the need for high quality maritime communication technology in Arctic areas. High quality means primarily sufficient bandwidth and adequate reliability. Shut-downs of the communication link from time to time can not be accepted. To be able to implement the possible solutions depicted in section 3 of this paper, stable communication channels are needed between land and sea, and also ad hoc networks at the emergency site. The pertinent maritime communication technologies can roughly be divided into three domains:

– Satellite communications (SatCom), comprising so called Low Earth Orbit (LEO) satellites, Geostationary (GEO) satellites and High Elliptical Orbit (HEO) satellites
– Terrestrial wireless communications
– Ad hoc communication networks

As can be seen from the Figure 6 the present situation for satellite communication in Arctic areas is far from satisfactory. Only the LEO-based Iridium system has allegedly 'true' global coverage. The newly launched Iridium service OpenPort can offer up to 128 kbps capacity, which might be sufficient for transmitting operational messages during and emergency operation. However, if video and images shall be conveyed to land stations for real-time monitoring of the operation, this service is also rendered useless.

Another problem with Iridium is its dubious latency (the time delay due to data relay), and hence being doubtful for time-critical applications.

The limitations of GEO satellites in Arctic areas are:

– They are invisible at latitudes beyond 80°N (grazing incidence), and it is challenging to achieve a stable communication link beyond about 76°N (5° elevation).
– Complex (and expensive) antenna platforms are required at these latitudes, so in practice the GEO satellites are usable only up to about 70° N for moving vessels.

A preliminary study performed in the MarCom project states that 'the only adequate SatCom alternative for the High North is apparently to be based on HEO satellites' (Bekkadal, 2009). This is due to the convenient satellite orbits of the HEO's, covering the northern hemisphere for a large time of the day, and a

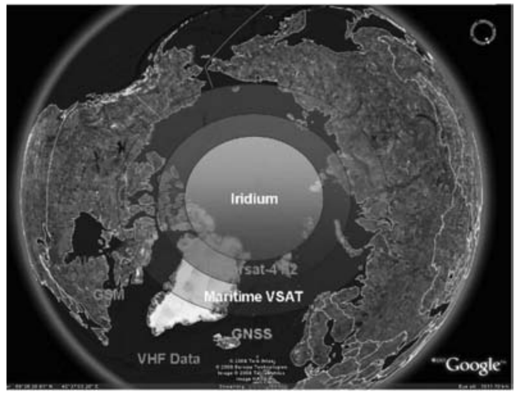

Figure 5. Maritime communication systems coverage areas.

3-satellite constellation would be sufficient to provide this area with a 24/7 service. However, this needs to be further analysed both in terms of technology and cost/performance. Such a development would require cooperation with other countries bordering the Arctic areas, such as Russia, Canada, Finland, Iceland, Denmark (Greenland), Sweden and the USA, which could very well be organised under the auspices of the Arctic Council.

The coastal areas (including the Northeast and Northwest passages) are judged to be adequately covered by deploying terrestrial systems along the coast – WiMAX and enhanced Digital VHF being considered the most promising future alternatives. However, the cost and complexity of such systems would require a detailed study of a.o. the area's topography (Bekkadal, unpublished).

Ad hoc networks are in use today by both SAR teams and in military operations. Ad hoc networks do not really depend on the position on earth because the network comprises only the nodes within a limited area. However, it would be very convenient if the ad hoc network could be monitored from operational centres ashore, which would require a satellite or terrestrial link with sufficient bandwidth and high integrity – integrity meaning the link being trustworthy.

3.3 *Application software (SW) tools*

The Wikipedia definition of an application SW is: "Application software is any tool that functions and is operated by means of a computer". Some applications could be developed to meet the challenges posed by emergency operations in Arctic areas. These applications could be used both in planning and execution phases of the operation. An example of a planning tool is the contingency plan, including features such as optimum selection of rescue resources. Examples of such resources are tugs and oil recovery equipment specially designed for operations in Arctic areas.

The need for enhanced equipment and applications on board vessels should also be considered in facilitating improvements to the process of emergency operations. Often it is a "normal" vessel that reaches the emergency scene first, obviously not having the same on-board equipment and applications as a SAR vessel. New requirements for a minimum set of Arctic SAR applications and equipment on board vessels should be considered, which needs of course to be combined with classification of vessels. By introducing such requirements all vessels could amply assist other vessels in distress until the SAR team arrives.

Another issue that should be investigated is prioritising mechanisms on communication channels usage. This is especially important in the time to come before the communication infrastructure is fully developed in the Arctic areas, which may take some years. The prioritising mechanisms should automatically provide exclusive access to sufficient communication capacity to ensure high availability and integrity of channels used by all partners involved in the emergency operation.

Ice related applications are of course also very important in the Arctic areas. This is the case both during normal sailing in the Arctic areas, and during emergency operations. Possible applications are:

- Calculations and visualisation of ship performance in different ice conditions, which could be used both to avoid dangerous situations during normal seafaring, and for analysis during emergency operations.
- Recognition of sea ice characteristics (compactness, thickness, icebergs) by satellite images. This is already to a certain extent used by navigators on vessels sailing in ice-covered waters.
- Features of rare ice drift around e.g. Svalbard and in fjords. This could also be used to enhance the safety of a voyages in ice-covered waters, and for analysis during emergency operations.

4 E-NAVIGATION IN THE HIGH NORTH

Some of the solutions on applications and communications proposed in the above sections should also be considered during the development of the IMO e-Navigation concept. The IMO has adopted the IALA definition of e-Navigation, and it says (NAV sub-committee, 53rd session, 2007):

"*e-Navigation is the harmonised collection, integration, exchange, presentation and analysis of maritime information on board and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment"*.

In remote areas, and especially in Arctic waters, this concept faces extraordinary challenges. It is e.g. difficult to collect, integrate and exchange maritime information if there are no available communication channels. Also, the need for special purpose e-Navigation services in Arctic areas should be considered. The extreme navigational challenges due to low temperatures, ice and harsh weather conditions require more specialised services than in other more centralized areas. E-navigation can become an important part in a future safety and security concept for Arctic areas if these requirements are fulfilled.

5 CONCLUSIONS

It is important not to forget the experiences from the Maxim Gorkij and other similar accidents having occurred in the Arctic and Antarctic areas. They can help in providing a clear view on what type of information, data, communication infrastructure and SAR resources required to be developed. The main lessons to be learned from the Maxim Gorkij accident is that in order to be able to conduct efficient and safe emergency operations, more crucial information needs to be available to all parties involved. This could be in terms of supporting decision tools and information from operation centres ashore. However, nothing of this is possible without a maritime communication infrastructure with sufficient bandwidth and adequate integrity. This important task should consequently be immediately addressed within the maritime community.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

11.3
Ice conditions and human factors in marine accidents at the Arctic

N. Marchenko
The University Centre in Svalbard, Longyearbyen, Norway
The Norwegian University of Science and Technology, Trondheim, Norway
State Oceanographic Institute, Moscow, Russia

ABSTRACT: All activities in the Arctic are conducted near the limit of technological opportunities and human abilities. But the drain of resources in the areas convenient for development obliges us to look at this severe polar region. The main objectives of the PetroArctic project (offshore and coastal technology for petroleum production and transport from arctic water) as a part of PETROMAX and MarSafe project (Marine Safety Management) are to obtain and provide information for safety of Arctic operation such as hydrocarbons production and transport from Polar seas. One of the tasks is a collection of ice pilot experiences from the people involved in the Arctic activities to learn how they felt in these conditions, how they solved difficult tasks and managed the ice. Items of special interest are connected to lost vessels and other marine accidents. Appreciable amount of written documentation and interviews have been processed and organized into a data base of marine accidents in Russian Arctic since 1900. It includes a set of maps where the locations of the accidents are shown with a description of the accidents (date, geographical environment, vessel type, what happened and how the people acted, etc). This paper includes the map for Kara Sea and descriptions of several accidents in the eastern part of Arctic as example of different situations, as well as the principles of the data base construction and accidents classification.

1 INTRODUCTION

For a modern development of the operation in the northern seas it is very important to learn from the previous ice pilot experiences. Russian sailors have for many centuries experienced the navigation in the ice conditions. As seafarers the pomors (inhabitants of Russian North) dominated an enormous zone from the shore areas of White, Barents and Kara seas to the archipelagos of New Land and Spitsbergen since the 16th century. The major factors which allowed pomors to overcome the difficult and challenging Arctic routes were the usage of specialized ships, called "koch", and inheritable skills and customs.

Through the centuries Russian sailors accumulated extremely impressive skills for the operations in the Arctic waters. The experiences of the Russian ice pilots were summarized in the special textbooks for the future captains. There are at least 9 such textbooks written by captains who took part in the Northern Sea Route cruises (for example, Arikaynen, Chubakov, 1987, Gotskiy, 1957). The first such textbook was published in 1940. Key points of the Russian Arctic history and specifics of the seas are well known to the foreign society and researchers as well as it was presented in articles by Terence Armstrong (1952) and William Barr with co-author (Barr, 1974–1985), working papers of INSROP (International Northern Sea Route Programme, June 1993 – March 1999), CRREL (Cold Region Research and Engineering Laboratory) reports and others. The translations introduced western audience to the most important and dramatic pages of the NSR history, such as, for example, the cruise of *Sv. Anna* and Al'banov's sledge journey (Barr, 1975), the Rusanov's *Gerkules* expedition in the Kara Sea in 1913 (Barr, 1984) and the shipping crisis in the eastern Arctic at the close of the 1983 navigation (Barr, Wilson, 1985).

However, some pages of this heroic epic are not known even in Russia. The investigation of the Russian ice pilot experience has become very relevant nowadays in the light of new activities in oil-gas exploration spreading out in the Arctic and the new transportation possibilities appearing due to the global warming.

Information about Russian activities in the Arctic is gathered in the frame of the PetroArctic and MarSafe projects. The data about extreme situations (ice drift and ice jet, icing and hummocking, ridging ice opening and closing, etc) and special weather and ice conditions are collected. Items of special interest are connected to the shipwrecks and other accidents. Data about vessel type, location and time of wrecks and damages, weather and ice conditions, description of events has been organized into a data base. To prevent the future losses we need to know where and when accidents used to take place, under what weather and ice conditions, what happened and how did the crew react. For many accidents the information on distinguished features and the behavior of humans in the Arctic waters (reactions in stressful situations and reasons for deaths) has been collected. The most original part of the presented investigation is a set of maps showing the accident locations and the ways of ice drifts.

Only accidents connected with the ice conditions that reveal the role of human factors are taken into consideration in this paper. Analyzing marine accidents in the Arctic enables us to find a whole series of events when the wrecks were not avoidable due to extremely difficult circumstances. But there are also accidents when the ice conditions looked rather good and nothing denoted on the approaching disaster. The rest of the events fall in between the two extremes.

2 EXPLORING OF MARINE ACCIDENTS IN THE ARCTIC

2.1 *The objectives and sources of information*

The objective of this investigation is to increase the knowledge about ice conditions and human reactions for safety in the Arctic region. The main aim is a sustainable development and exploitation of the Arctic region. The collection of the ice pilot experiences is a mixture of history, geography, technology and sometimes psychology, because we have to know how people operated in the Arctic and how they solved difficult tasks, how man would feel and act in the extreme conditions. The investigation presented in this article is devoted mainly to the accidents induced by the natural causes in the Arctic since 1900. The detailed descriptions of such accidents can give us not only great examples of a heroic behavior, but also provide information on natural, weather and ice conditions and show special techniques used by crew to survive.

Among the different sources of information are museum exhibits and written documentation, books and journals, newspapers and internet articles as well as oral evidences of the persons involved. The most thrilling part of the work is interviewing ice masters, mates and pilots. They can be found in special communities and on real vessels. Several organizations affiliate people like that, such as Russian Geographical Society with Department of Polar Region Geography and Association of polar researchers and polar workers, integrating remarkable people with extraordinary fates, connected to sea ice. Conversations with them are newsworthy and entertaining. The same applies to interviewing the people on board the vessels, who brave ice out almost every day and can demonstrate actual techniques and provide real life documentation such as check-lists.

2.2 *Marine accidents classification*

For our purposes we can divide all the accidents into two main groups: with ice and without ice. There are four main groups among the accidents in the ice conditions. These are forced drift, forced overwintering, shipwrecks and serious ice damage when the crew has managed to rescue the ship with the help of other vessels. Both forced drift and forced overwintering can have lethal outcome (Look for example № 3 the map – figure 1). Among the accidents without the ice we can distinguish shipwrecks and serious damage.

All these types of accidents are quite received and understandable. But there is a special case of forced drift deserving of particular attention, as this is not very common in the international science literature. This is so called ice jet, the forced drift with considerable speed. Ice flow in ice jet is so powerful that even the modern icebreakers can not resist it. This phenomenon has been described by V. Kupetskii (Kupetskii, 1983) and modeled and mathematically presented by V. Benzeman (1989). V. Benzeman (1989) determined “ice jet” as “non-stationary jet stream of compact ice cake, sometimes with compressing, drifting with high velocity near the boundary of the fast ice or motionless ice massif in a strait, bay or open region of freezing sea”. Ice jet displays itself as a drift with huge speed and has lead to shipwrecks several times. The shipwreck of freighter *Nina Sagaidak* in Chukchi Sea, October 1983 is a great example. Before she sank, she was slammed to the freighter *Kamenesk-Ural’skii*, while they drifted helplessly apart (see also, Barr, 1985). (see father).

3 ACCIDENT DATA BASE

It might no be completely accurate to call our collection of accidents a data base, because not all of the accidents in it are presented with equal accuracy and under the same circumstances. There are sets of books, movies and other information available for the most famous shipwrecks such as *Sv. Anna* (1912–1914) and *Cheluskin* (1934). Other vessels are represented by pages of several reminiscence and sets of photos, but have only mentions about the essential parts of accidents. The main task remaining is to accumulate as much information as possible and organize it in an appropriable way.

Massive amount of data is organized both geographically and chronologically. It includes a set of maps, tables and connected files. The maps for each Russian Arctic sea show accident locations. Explanation of the maps lists the dates, names and types of the ships with accidents itemized according to their types (see above). More detailed maps reflect explicit accident location, lines of ship drift and ice conditions if available. The numbers on the map correspond to the numbers in the table 1 with a short description and a destination of the folder with detailed description.

3.1 *The Kara Sea example*

As an illustration of the “Accidents data base” construction the short extraction for the Kara Sea is presented here. The example includes only one map (figure 1) for accidents which had been induced by hard ice condition, explanation to the map and the beginning of the table 1 with short description of the accidents. It should be stated that the ice drift has usually very complicated and chaotic configuration and

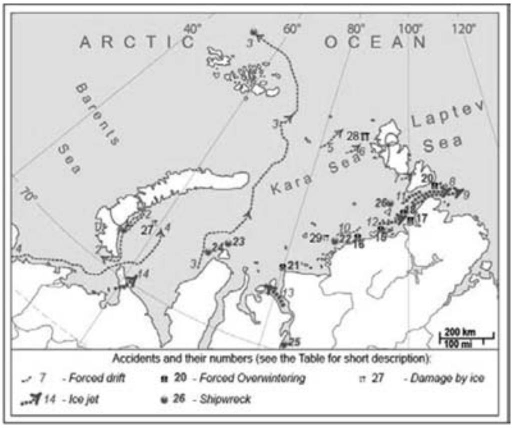

Figure 1. Accidents in Kara Sea since 1900, induced by ice conditions.

Explanation to the map "Accidents in Kara Sea since 1900, induced by ice conditions (figure 1)

Forced drift with ice – 14

1 – 1900. September–October. Wooden yacht Mechta
2 – 1907. July–August. Research vessel Belgica
3 – 1912–1914. Wooden schooner Svyataya Anna
4 – 1920. January–June. Steamer Solovey Budimirovich (later recalled to Malygin).
5 – 1930. August (7 days). Icebreaking steamer (IS) Sedov.
6 – 1934. (23 days). IS Sadko.
7 – 1936. (28 days) IS Sibiryakov.
8 – 1937. August. IS Sadko.
9 – 1937. September. The whole caravan of vessels with IS Yermak.
10 – 1937. Summer. Several weeks. Research vessel Professor Vize.
11 – 1963. October. Caravan of vessels with icebreaker Lenin
12 – 1963. October. Steamer Novovoronezh.
13 – 1977. November. Icebreaker Captain Sorokin.
14 – 1980. March–April. 2 nuclear icebreakers Sibir', Arktika and icebreaker Kiev.

Forced overwintering – 7

15 – 26. September 1900–30. August 1901. Schooner Zarya
16 – 12. September 1914–11. August 1915. Schooner Eklips
17 – 9. September 1914–2. August 1915. IS Taymyr.
18 – 9. September 1914–2. August 1915. IS Vaygach.
19 – Autumn 1936–summer 1937. Survey vessel Toros.
20 – October 1937–June 1938. Almost half of the transport vessels (26 ships) and the entire icebreaker fleet (7 icebreakers) overwintered in the Arctic. Litke, Mossovet, Uriskiy, Pravda, Krest'yanka, Molokov were beset at the south-east cost of Bol'shevik Island.
21 – October 1937–June 1938. 6 cargo ships

Shipwreck–5

22 – 1912–1913?. Sealing ship Gerkules
23 – 1921. 17. September. Steamer Enisey.
24 – 1921. 20. September. Steamer Ob'.
25 – 1924. Schooner Agnessa.
26 – 1985. June. Freighter Nina Kuroverova.

Damage by ice–3

27 – 1933. August. Steamer Cheluskin.
28 – 1937. August. Icebreaking steamer Sedov.
29 – 1937. August. Freighter Sura.

only the main direction without any loops and zigzags is presented on this map. References in the table 1 are given on only the essential sources in Russian and in English.

3.2 *The accident examples*

The two events in eastern sector of the Arctic will be described below as an example of the accidents. The first one is about a human factor, the second one illustrates the invincible natural forces action. See photo and location on fig. 2,3.

3.3 *Example 1. 1955. East-Siberian Sea. Motor vessel Kamenets-Podolsk*

Accident with motor vessel *Kamenets-Podolsk* have been described in the reminiscences of captain Pacel Kuyantsev (1998). At the end of September 1955 she sailed from the Ugol'naya bay to the cape of Shmidta (Mys Shmidta) with a full load of coal. She was convoyed by an icebreaker. But northern winds brought a lot of heavy ice and made further movement impossible at the distance of 50 km before the aim. The ships waited the whole earth-day and after that gave the order to go back to Pevek. The ice condition was very hard till Mys Billingsa and the speed was extremely slow. The case demanded skilled use of energy and concentration of everybody's attention. To the west of Mys Shalaurova the conditions improved and the compactness of ice decreased to 5 balls. The exhausted crew respired, captain was able to afford a short coffee break and went down to his cabin. He had left the bridge for only 10 minutes, but when he returned, he immediately realized that an unavoidable accident was already unfolding. An ice-free clearing spread before the bow had been left by an icebreaker sailing half a mile ahead. Pieces of ice drifted here and there. Their position relative to the ice field was changing. The second mate noticed a small piece of ice and thought it was also floating separately from the ice field. When he put the helm to port to avoid it, Captain noticed at once that this piece of ice was not moving and realized it was the top of a submerged ice ledge. It was too late to turn starboard. At the vessel's speed of about seven knots, a submerged ice ledge, if collided with the fore holds, could rip the vessel from the bow to the bridge. The only decision at this point was to stop the vessel. "Back_Full" command was given and it worked at once as forward motion was reduced. However, the propeller operation astern caused the moving vessel's bow to swing to starboard at the speed of 4 knots, brushing the forward port quarter against the ice. The terrible racket of tearing metal was heard and the vessel listed sharply to starboard. Captain turned the key for general alarm and immediately heard a splashing sound of a waterfall as water rushed into the hull to the first hold, maybe to the second hold, and the forepeak. The hole was 1 meter × 1 meter in the size and an opening of 10 cm wide also appeared in the stern after collision. The ship was settling down quickly bows on,

Table 1. Short description of accidents in Kara Sea since 1900, induced by ice conditions.

№	Short description	References	Links
	Forced drift with ice – 14		
1	**1900. September–October. Wooden yacht *Mechta*** (led by A.A. Borisov). Forced drift with ice along the east coast of South Island Novaya Zemlya since the end of September. The crew left her at 10. October 1900 and walked and swam through the ice, reached the land near the mouth of Savina River, crossed Novaya Zemlya and arrived to Pomorskaya Guba at 12. November 1900.	Vize, 1948	http://www.solovki.ca/art/borisov.php
2	**1907. July–August. Research vessel *Belgica*** (led by Philippe duke d'Orléans). Nipped by the ice in Matochkin Shar at the end of July. Current carried her with the ice to the south and drove upon Barents Sea through Kara Gate (16. August 1907), saved by herself.	Vize, 1948	
3	**1912–1914. Wooden schooner *Svyataya Anna*** (captain Brusilov). The ship became beset just west to Yamal Peninsula in October 1912 and drifted steadily northward in the ice. By April 1914 she was still drifting 100 km north of Franz Josef Land and further to the north – Evidently wrecked – Crew dead, except for 2 men (V. Al'banov, Konrad) who managed to reach Franz Josef Land.	Al'banov, 1917–1978, Barr, 1978	http://www.kapustin.boom.ru/journal/albanov01.htm http://www.rusk.ru/st.php?idar=708035

These accidents had been described by Yu. Vize (1948), M. Belov (1959), Pinkhenson (1962), V. Kupetskiy (1983), Benzeman (1989) and other. There is also information in English (Barr, 1974, 1984, etc).

the stern was lifting dangerously. Captain was ready to give the order to leave the ship and go down to the ice. But in a minute the dressed sleeping staff was on the place and rescue operation began.

In seven minutes patch was placed and the bow stopped submerging. The first and second holds were opened. The first hold was filled up to the sea level and over a half of twin deck. The bow submerged under water up to the anchors. Fortunately the screw and the helm were in the water as she moved by the stern before collision (trim was near 1 meter). It was impossible to pump the water away, because the pipes were blocked by the coal. But water lever in the holds rose up very slowly. After discussions it was decided to continue the voyage and sail to the cape behind the icebreaker with low speed while monitoring water in the holds. *Kamenets-Podolsk* reached the port of Pevek at a speed of 10 knots.

Two jokes spread to ice pilot society after that accident. The first lesson was that during Arctic Navigation the captain "should drink coffee on the bridge, not downstairs". When captain Kuyantsev reported that it was his mistake due to inexperience in his first ice navigation, the chief of the headquarters M.V. Gotskii (very famous and revered captain) replayed that according to Russian tradition, arriving of ship with crushed stem is not a dishonor for captain, it is the sign of his sureness and courage. But if the screw and the helm were broken, captain has to feel the shame.

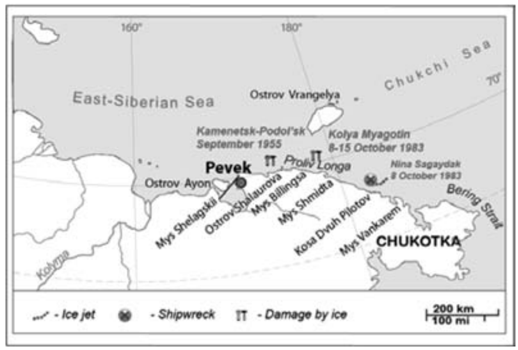

Figure 2. Location of accidents.

Figure 3. Nina Sagaydak sinking http://www.yaplakal.com/uploads/post-3-12340193324991.jpg.

3.4 *Example 2. 1983. Chukchi Sea. Freighter Nina Sagaidak (figure 2,3)*

The second accident to be described here is a well-known shipwreck of freighter *Nina Sagaidak* in Chukchi Sea during terrible ending of navigation season(?) in 1983. An unusually early freeze-up and persistent northwesterly winds that drove heavy multi-year ice into Proliv Longa and against the north coast of Chukotka resulted in a critical situation. During September several ports were prematurely closed by ice, leaving Pevek as the only functioning port in this part of the Arctic. Dozens of ships were beset. Practically all available ice breakers were transferred from the western to the eastern Arctic to free the jammed ships. Many ships were forced to head west from Pevek to the Atlantic, rather than attempt to battle their way through the heavy ice in Proliv Longa in order to return to their Pacific home ports. One early report put the number of damaged ships as being in excess of 30 (Bratchikov, 1983). Fortunately, there were no lives lost.

Let's remember this event in English presentation by W. Barr and E. Wilson (Barr, Wilson, 1985)

"Early in October the freighter *Nina Sagaydak* one of a convoy of ships westward bound to Pevek that was caught by the ice near Kosa Dvukh Pilotov, a little to the east of Mys Shmidta, found herself in serious difficulties. Built at Rostock, East Germany, by the Schiffswerft Neptun in 1970, *Nina Sagaydak* was one of a class of 31 almost identical small freighters of between 341 1 and 3684 gross tons; she was 105.7 m long, with a beam of 15.65 m and engines of 3250 bhp, giving her a top speed o1f 3.75 knots. On *6* October 1983 the freighter *Nina Sagaydak* was caught in multiyear ice 3-m thick being driven against the edge of the fast ice, and soon irresistible ice pressures began to build up. Massive pressure ridges piled up against her sides, with enormous ice blocks tumbling over her rails. Her stern was forced against the fast ice and her rudder and propeller were jammed. To compound the difficulties the freighter next collided with the tanker *Kamensk-Urul'skiy*, also drifting helplessly in the ice. For over half an hour the ships ground against each other, and despite frantic efforts to place fenders between the two hulls, both ships received some damage; *Nina Sagaydak* came off worst. Her crew was rather startled to *see* the tanker's crew pouring water down the sides of their ship at the points of contact between the hulls in case sparks caused by the grinding and pounding might ignite fumes from the tanker's cargo. The two ships ultimately drifted apart, but even worse was in store for *Nina Sagaydak.* As the ice pressures continued, her hull plates began to crack and the water began to rise inexorably in the engine room. Despite every effort her pumps were unable to cope with the enormous influx of water and the ship began to list heavily to starboard. When the list had reached the alarming angle of 40° the chief engineer brought all his men on deck and the captain gave orders for the crew of 45, and a further 6 men accompanying the ship's cargo, to be lifted off by helicopters from the icebreakers *Kapitan Sorokin* and *Vladivostok*, which were standing by, unable to save the sinking vessel. The ship stubbornly remained afloat, held up by the ice and with her engines and pumps still running unattended for almost a day. Finally, early on the evening of 8 October, while her crew watched helplessly from *Kapitan Sorokin* barely a ship's length away, *Nina Sagaydak* sank by the head. Her crew was flown south to Vladivostok, and a commission of enquiry into the loss of the ship was convened at Pevek. It concluded that no blame attached to any of the officers or crew members and that everything possible had been done to save the ship".

On the day after *Nina Sagaydak* sank, her sister ship *Kolya Myagotin* was caught between two massive ice floes and badly holed (see figure 2). As a precaution most of her crew was evacuated by helicopter and only five of the crew battled to keep the ship afloat and they managed to rescue her. But it is another story.

4 CONCLUSIONS AND ACKNOWLEDGEMENTS

Creation of Accident Data Base is not finished yet because of the new circumstances and details that have been and can be found. It seems to be an endless process. But even now this set of accident descriptions can be useful for understanding the ice, weather and human conditions in the Arctic and for planning the future activities in this severe region. A more thorough review of the "data base" is, however, in preparation (Marchenko, 2009).

This study is founded by the PetroArctic project and the author acknowledges The Research Council of Norway for the financial support which was provided by the PETROMAKS program and PetroArctic as a part of the PETROMAKS. The author appreciates Prof. Ove T. Gudmestad and Prof. Sv. Løset for the original idea and helpful discussions and thanks the staff of the libraries at State Oceanographic Institute and Arctic and Antarctic Research Institute.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

11.4
Sea Ice Services in the Baltic Sea

M. Sztobryn
Institute of Meteorology and Water Management, Maritime Branch, Gdynia, Poland

ABSTRACT: The Baltic winter navigation depended always very much on the ice conditions in the sea. The sea ice occurs different in form and amount, depending on the sea area and the winter season. As the maritime traffic on the Baltic Sea constitutes a substantial amount in the whole of the Baltic countries transport, Sea Ice Services (SISs) have come into being. They constituted the Baltic Sea Ice Meeting (BSIM) – a body, which assembles the parties, which are interested in warnings against bad ice conditions, and in protection of navigation in ice in the Baltic Sea. An indispensable co-operator to this body was always the company "Baltic Icebreakers". To-day within the BSIM operate by the SISs of Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland and Germany, Netherlands, Norway and the Baltic Icebreakers. The main statutory duties of the SISs is the acquisition, processing and dissemination of actual information on sea ice conditions and on obstructions to navigation due to sea ice. This is done by maintaining observing posts along the coast of those countries, in their ports and approaches to them, by gathering information from ships, from ice beakers, if possible – from reconnaissance flights or satellite images. Routine products of SISs are the ice reports, ice bulletins, ice charts, forecasts and warnings and other information broadcast by mass media, e.g. radio, internet, Navtex and on the national and Baltic SISs' web sites etc.

1 ICE CONDITIONS IN THE BALTIC SEA

Baltic Sea is a semi-closed, tide less and comparatively dismembered sea. Its low salinity varies from about 20‰ in the Belts waters to about 1‰ to 4‰ in the north-eastern basins. The differentiation of salinity, bathymetry, the latitudinal and continental (climatic) influences generates significant inhomogeneity of freezing conditions in different basins of the sea. Some of the basins freeze each winter, the other only rarely, during exceptionally severe winters. In order to be able to compare the winter conditions in different years or in different basins of the sea, some scales of winter severity are in use. According to one of them (sea ice severity index S_{reg}, after Sztobryn et al., 2008) three types of winters were distinguished (mild, normal and severe) and a classification of winters between 1955 and 2005 in the Baltic Sea was made, as in Table 1.

Highest values of sea ice index S_{reg} were characteristic for the Bay of Bothnia, where they oscillated between 9,32 in 1980/81 and 5,34 in 1991/92. The lowest values of S_{reg} were gained in the Western Baltic, with the minimum equal to 0,0, what occurred for eight times in the investigated 50 winter seasons, while the maximum value there was as high as $S_{reg} = 5{,}72$ in 1995/96. Quite close to the values representative for the Western Baltic were the extreme conditions in the Aland Sea and the Archipelago: maximum value of S_{reg} reached there 5,89 in 1969/70 and the minimum value was 0,0 (for four times).

The values of basic S_{reg} statistics, when compared, allowed to distinguish three groups of regions considered here, which were similar to each other with regard to the sea ice conditions.

The first group, the "mild winters zone", consisted of the Western Baltic Sea, Southern Baltic Sea and the Aland Sea; the second group, the "normal winters zone" made the western Gulf of Finland and the Sea of Bothnia. Into the third group, the "severe winters zone", were included the Norra Kvarken and the Bay of Bothnia, where the statistical parameters of S_{reg} were positively higher, than in the remaining considered regions of the Baltic Sea. It must be stressed that

Table 1. Number of winters of given severity in particular basins of the Baltic Sea in the winter seasons 1955/56–2004/05 (Sztobryn et. al. 2008).

Type of sea ice severity	Baltic	Western Baltic	Southern Baltic	Gulf of Finland	Aland & Arch	Sea Bothnia	Norra Kvarken	Bay of Bothnia
Mild	17	43	36	16	33	14	2	0
Normal	17	1	8	11	9	11	4	0
Severe	16	6	6	23	8	25	44	50

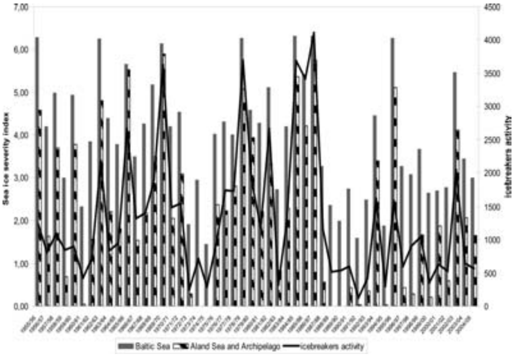

Figure 1. Long term icebreakers activity variation (in annual number of assistance cases) compared to winter severity (represented by the sea ice severity indices) during the winters 1955/56–2004/2005.

though very characteristic, the above cited indices did not involve all areas of the Baltic Sea, as for instance, the south-eastern coasts of the central sea parts.

There exists a high proportionality between the values of the indices S_{reg} and the number of icebreaker assistances, requested by all kind of vessels plying between the coasts of the Baltic Sea. The icebreakers are ready to assist any ship on the ice obstructed routes of the Baltic Sea, from the Belts to the farthest ends of the Bothnia Bay or the Gulf of Finland. Varied ice conditions in the Baltic Sea cause much greater navigational difficulties in the northern and eastern parts of the sea. One of the indicators of those difficulties is the number of cases, in which the assistance of icebreakers is indispensable. For instance, in the 50 years considered here, the number of assistances of only the Swedish and Finnish icebreakers varied from 121 in the winter season 1991/92 to as many as 4107 during the winter 1986/87 (Grafstrom & Kiggren, 2007). The relationship between the ice severity (by the severity indices for Baltic Sea and Aland Sea) and icebreakers activities (number of cases, in which the Swedish and Finnish icebreakers assisted the ships) is presented by the comparison, of how these two winter features varied during the 50 winters of 1956 – 2005 (Figure 1).

The seasonal sea ice severity is presented by the ice severity index S averaged over the whole Baltic Sea and regional, and the ice breakers activity is shown in number of cases, in which icebreakers assisted the ships. It must be stressed here that the BSIS are always supported by both the icebreakers and the ship masters in gaining actual information on ice conditions on their sea routes.

2 THE SCOPE OF ACTIVITIES AND ORGANISATION OF THE BALTIC SEA ICE SERVICES

The Baltic winter navigation depended always very much on the ice conditions in the sea. The sea ice occurs different in form and amount, depending on the

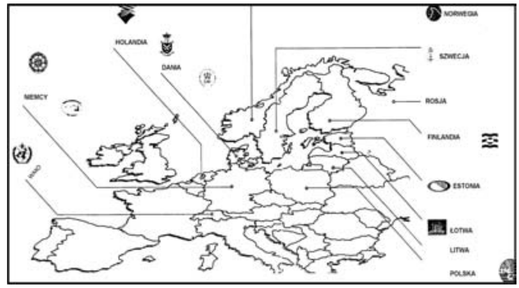

Figure 2. Sea Ice Services in the Baltic Sea Ice Meeting.

sea area and the winter season. As the maritime traffic on the Baltic Sea constitutes a substantial amount in the whole of the Baltic countries transport, Sea Ice Services (SISs) have come into being. They constituted the Baltic Sea Ice Meeting (BSIM) – a body, which assembles the parties, which are interested in warnings against bad ice conditions, and in protection of navigation in ice in the Baltic Sea. An indispensable co-operator to this body was always the company "Baltic Icebreakers". To-day within the BSIM operate by the SISs of Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland and Germany, Netherlands, Norway and the Baltic Icebreakers (Fig. 2). The main statutory duties of the SISs is the acquisition, processing and dissemination of actual information on sea ice conditions and on obstructions to navigation due to sea ice. The existence of BSIM and cooperation between SISs guarantees the use of standardised ice messages, codes, graphic symbols, formats, etc in the ice data exchange not only between all these countries but also for navigators.

BSIM as well as SISs is working on two levels – the national one and the international.

The national level involves:

– network of coastal observing posts,
– data collecting centre,
– Sea Ice Service National Centre

The Sea Ice Service National Centre is responsible for:

– acquisition of all possible ice information (from beyond the routine ice observing network data) as icebreaker data, satellite data, air reconnaissance data etc,
– data control and interpretation,
– edition and dissemination of ice information in form of ice reports, ice bulletins, ice charts etc,
– forecasts of ice conditions development,
– exchange of ice information – locally, and in the region – internationally,
– co-operation with icebreakers.

The international level demands for:

– daily routine exchange of ice information products between the Sea Ice Services,
– international co-operation with Ice Breaker Service,
– participation in BSIM conferences in order to asses the activities of the National Sea Ice Services, to

implement the developing technologies into these activities and to adapt these activities to changing economic and political conditions,
– co-operation with the WMO, JCCOM as well as with International Ice Charting Working Group (IICWG).

Between the BSIM conferences, the activities of the Sea Ice Services are co-ordinated by the representatives of the National SISs, under the leadership of the acting BSIM Chairman.

3 SHORT HISTORY OF THE BALTIC SEA ICE SERVICES

Importance of the winter navigation in the Baltic Sea on one side and on the other – serious sea-ice borne difficulties, forced in the regions of severe winters regular sea ice observations already in the middle of 19-th century. This, however, was initiated by individual countries (the economy of which mostly depended on sea traffic, also in winter). Therefore the first observations were carried out only in those countries, with no integration on larger scale.

The tragedy of "Titanic" powered to create the first in the world, a completely organised, world wide sea ice service (International Ice Patrol). In this time Europe began also to develop the protection of winter traffic in sea ice conditions. However the World War 1 and the following formation of new political systems on the continent did not allow to meet the Baltic ice experts earlier than in 1925 (Strubing 2003). That ensemble of experts on protection against sea ice discussed the in that time available instruments of information exchange; among others they proposed the use of the Baltic Sea Ice Code (BSIC). Already in 1926, on the 1st Conference of the Baltic Hydrographers (CBO) in Riga the frames of data exchange standardisation had been settled, and one year later, on the 2nd CBO, the first BSIC was accepted. The recommendations of this Conference were implemented very soon, and already in the severe winter 1928/29 the majority of information, among them the ice charts, was used according to the uniform BSIC rules. In the year 1936, on the 5th CBO in Helsinki the status quo of the SISs was discussed, including reports on their organisation and activities. Also the sea ice terminology was completed and accepted, together with the multilingual terminology of the BSIC.

The World War 2 interrupted the co-operation within the BSIM. The National SISs, however, resumed their ice information exchange by the same rules as before, straight away after the war ended. Not earlier, however, than in the year 1954 the ice experts of Denmark, Finland, Federal Republic of Germany, the Netherlands and Sweden activated the BSIM to compile the International Sea Ice Terminology and to actualise the BSIC by enriching its content. Short after 1956 also the former German Democratic Republic, Poland and the former USSR sent their representatives to resume the co-operation within the BSIM. Further meetings of this body consisted in improving the information exchange technologies, in the revision and actualisation of BSIC and ice chart (among them the Sea Ice Egg Code), in completing the multilingual vocabulary of sea ice terminology, digitalisation of ice charts by introducing the SIGRID code and last, but not least, in implementing the mathematical prognostic models of ice conditions development into the operational routine. Successive years brought enormous development in both observation technologies (remote sensing, aircraft reconnaissance, radar and satellite imagery) and in data transmission (internet, Navtex, other mass etc). Successive BSIMs had to cope with that abundance of potentiality to be implemented into the Sea Ice Service observing practices, into data transmission and forecasting. Sea ice codes had to be repeatedly revised and completed, also due to political changes in the last decade of the 20th century. In the year 2005, on 21st BSIM in Riga the Memorandum of Understanding of the Sea Ice Services has been signed by the majority of the national services.

4 BALTIC SEA ICE CODE

This code is a set of conventional numeral symbols used in transmitting messages on ice conditions and obstruction to navigation due to sea ice in particular areas of the Baltic Sea, in ports and approaches to them and on other sea router (about 500 observational posts). After having collected all the ice messages from its region of responsibility, each individual SISs prepares national ice report/ice bulletins (Fig. 3) and transmits it to be broadcast by the Global Telecommunication System (GTS). The first edition (used as national code from 1920/21) of Baltic Sea Ice Code (from 1928/29) contained only two groups, specified as "j" and "k". Under "j" described were the ice conditions, under "k" – the obstruction to navigation due to the ice. The second BSIC established in 1954/55 (used in Poland from1963) and revised in 1969, was modified by adding another group on ice development. Now by "i" were meant the ice conditions, by "j" – ice development, and by "k" – impact on navigation by ice. The third BSIC has been introduced in 1981 and is till to-day in use. It described the ice conditions in ports, fairways and significant navigation channels. BSIC (in ice bulletins and reports) with ice charts give the detailed information for ships' officers of actual ice and navigation conditions. The sea and navigation areas of each country are designated by capital letters AA, BB, CC ets. Each area is subdivided into parts numbered from1 to 9. Baltic Sea Ice Code (Figure 3) consists of four groups:

A_B – amount and arrangements of sea ice,
S_B – stage of ice development,
T_B– topography or form of ice,
K_B – navigation conditions in ice

The receivers of the ice reports from the whole sea region use them, after having decoded them, to compile their routine products: ice bulletins, ice charts and

STPL42 SOWR 120758
POLISH ICE REPORT 120201
AA 10//0 24200 36241 44211 55312 65312
BB 11100 23000 31100 44320 57260 62000 77260
CC 18353 25213 35313 43213 55123

Figure 3. An example of Polish Sea Ice Report from 12 of Feb. 2001.
where CC18353 after decoding:
CC "1" = observational post; here Swinoujscie, Pomerania Bay,
"8" – fast ice,
"3" – grey-white ice,
"5" – rafted ice,
"3" – navigation without icebreaker assistance possible only highpowered vessels of strong construction and suitable for navigation in ice.

other information, e.g. the forecasts. Ice report/ ice bulletin is edited daily or weekly, depending on the severity of sea ice situation. Also ice bulletins, which give detailed ice situation in the whole Baltic Sea area are issued routinely, in national languages and additionally in English. Bulletins can be mailed in paper form or e-mailed to the users.

5 ICE CHARTS

Ice charts were one of the oldest methods to distribute the information on sea ice conditions and on the obstructions, which the ice could be to navigation. The first ice charts, which now are stored in archived form, were drawn already in the end of 19th century. As a routine product of the SISs, however, they were issued not earlier than about the nineteen thirties. The main aim of an Ice Chart is to project on a map the actual ice conditions in the given sea basin or route.

Thus, an ice chart is a graphic supplement of the ice information contained in the Ice Report/Ice Bulletin and is issued daily, when ice conditions are severe, or twice a week, when the winter is calm.

The form, in which the ice conditions were presented on the ice charts, depended on the contemporarily available presentation technologies and on the accepted graphic symbols. Important also were the ways by means of which the maps were distributed to the users, especially ship masters, icebreakers, port officers.

The oldest Polish archived Ice Chart is dated on winter 1929 and is reproduced in Figure 4.

The chart was issued by the Wydział Morski in Gdynia of the contemporary Państwowy Instytut Meteorologiczny (Polish National Meteorological Institute). Ice conditions were presented by numbers of code in due chart places and the degree of obstructed navigation – by different colours. Beside of the graphic presentation a general description of ice conditions was given in plain language in Polish, English and German. Additionally, a more detailed description of

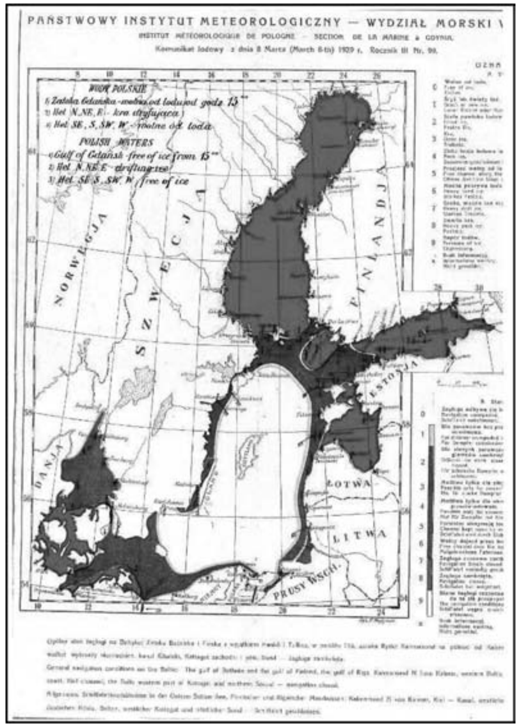

Figure 4. Polish Ice Chart from 8 of March 1929, issued by the Maritime Branch of the Pañstwowy Instytut Meteorologiczny in Gdynia.

ice situation in the Polish waters was given, including information on air temperature and wind. This, however, was a hand-made chart, delivered by messengers or mailed.

In the post-war decades, along with the telecommunication and other technical means development, the appearance of ice charts changed. When the facsimile transmission got possible, ready ice charts, in order to be transmitted to the addressees, had to be monochrome. Therefore, since 1981, new principles of one-colour drawing of ice charts were set. The Polish Ice chart had a conform conic projection and covered the area of the whole Baltic Sea, including Kattegat. Further, it gave all indispensable information on the ice conditions in the sea, the bays and lagoons.

Additionally, thickness of ice was added and names of icebreakers operating in particular sea areas could be inserted. However, preparation of an ice chart in that way was laborious enough (Fig. 5).

Further enormous development of the telecommunication facilities, as satellite links, internet, simplified both the transmission and preparation of ice charts and allowed for a come-back of coloured charts (Fig. 6).

Similar ice charts are edited by the majority of SISs, excluding Lithuania and Latvia. Russia reduces the area of its Ice Chart to the Gulf of Finland only, Estonia to the Gulf of Finland and the Gulf of Riga.

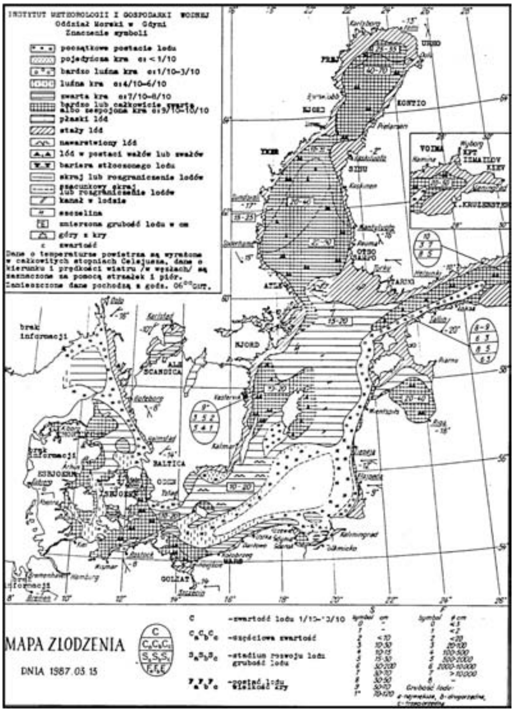

Figure 5. Polish Ice Chart from 13 of March 1987, edited by Oddział Morski IMGW in Gdynia (Marine Branch of the Institute of Meteorology and Water Management).

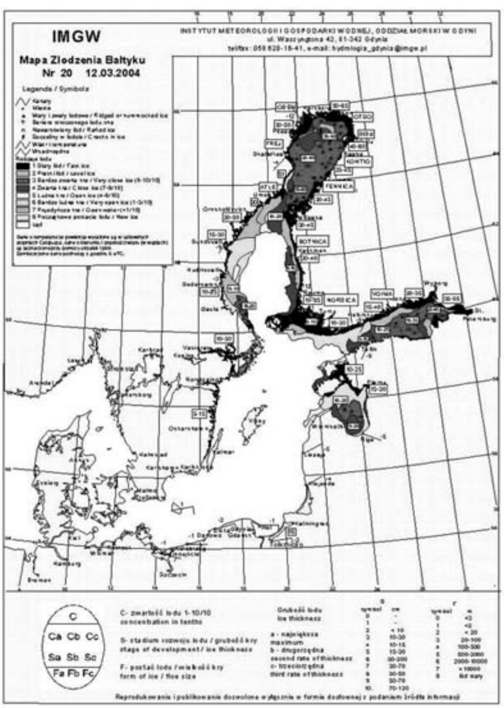

Figure 6. Ice chart of 12 of March 2004, issued by Oddzia³ Morski IMGW in Gdynia.

6 SUMMARY

The above discussed Baltic SISs' products (ice messages, reports, bulletins, ice charts and forecasts) do not involve the full list of sea ice information which is collected, processed and disseminated by these bodies. Merely mentioned were the ice development and movement forecasts. Also the users were scarcely mentioned, as the circle of users depends on individual needs of given country's national economy. Once more the role of telecommunication must be stressed. In previous ice seasons sea ice information was broadcast by radio, routinely with weather forecasts. Since nineteen nineties it is available by NAVTEX. Beside of this, the SISSs' products are published by internet – both on the web pages of the particular SISSs' as well as on the web of the BSISs. The investigation was made under the IMGW projects DS-H7 and project PL0 103 "Strengthening of the administrative capacity to improve management of the Polish coastal zone environment"- Seaman financed by the Norwegian Financial Mechanism.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

11.5 Low sea level occurrence of the southern Baltic Sea coast

I. Stanisławczyk, B. Kowalska & M. Mykita
Instytut Meteorologii i Gospodarki Wodnej, Oddział Morski, Gdynia, Poland

ABSTRACT: The level of 440 cm is defined as the upper limit of low sea level. This value is also accepted as the warning level for navigation, according to the NAVTEX. The low sea levels along the southern Baltic Sea coast were analyzed in the years 1955–2005. Lowest values recorded ranged from 309 cm in Wismar to 370 cm in Kołobrzeg. The phenomenon was chiefly generated by hurricane like offshore winds. Extremely low levels were not frequent, their occurrence did not exceed more than 0,3% in Świnoujście and not more than 1% in Warnemünde. In summer months these phenomena occurred extremely seldom, they were more frequent in the western, than in the eastern part of the coast. Long-term variation and statistical analysis was presented. Probability of low sea levels occurrence was calculated by Gumbel method and percentile distribution for 4 gauge stations was analyzed. The calculations revealed that, for instance, in Warnemünde once in 20 years the minimum sea level can be as low as 358 cm.

1 INTRODUCTION

The mean sea level in the Baltic Sea has visibly increased during the last century. The global generators of this increase may be supported or reduced by local influences. Routinely measured level values are the result of all the affecting causes. As some of these impacts appear irregularly in time, the resulting sea level changes are irregular, too. Daily oscillations of the levels at the southern coast may reach even 2,5–3 m in extreme cases.

Very low water levels may cause small harbours to fall dry and may cause obstructions to navigation. To ensure the safety of navigation in the difficult waters of the Southern Baltic Sea, reliable data on water levels, particularly low water levels, are highly important.

Low sea levels are one of the most important factors of the navigation safety. The practical importance of water level for shipping and harbour engineering was recognized early. Representatives of shipping are always deeply interested in safe passages of their vessels through the Baltic Sea, where at particular coasts significant differences in the water level are known to occur, in spite of negligible tides, nearly lacking in this sea.

Analyzed were the low sea level events at the southern Baltic Sea coast, basing on 50 years long series of sea level data from 1955 – 2005. The mareographic records were obtained from the water gauges in Wismar, Warnemünde, Sassnitz, Świnoujście and Kołobrzeg. The investigation was realized by Instytut Meteorologii i Gospodarki Wodnej – Oddział Morski (IMGW OM) from the Polish side and by Bundesamt für Seeschiffahrt und Hydrographie (BSH) from the German side. Used were the hydrological and meteorological data stored in the BSH and the IMGW archives.

This study on low sea levels occurring at the southern Baltic Sea coasts was realized as an internal IMGW and SEAMAN projects.

2 NATURAL CONDITIONS

The here considered section of the South-western Baltic Sea coast comprises, going east, three German water gauges, Wismar, Warnemünde and Sassnitz, and two Polish ones, Świnoujście and Kołobrzeg. The westernmost part of the southern Baltic coast between Wismar, on the Mecklenburg Bay, and Cape Arkona on the island of Rugia extends roughly from southwest to northeast. This part of the coast has a highly variable topography: it is shallow and rich in creeks, shoals, and sandbanks. Also the coastal section extending from the high cliffs of Cape Arkona to Świnoujście and the Odra estuary, oriented from northwest to southeast, has an intricate topography: it is rich in small sandy coastal islets, narrows, and sandbanks. In the adjacent Pomeranian Bay, the seabed also is highly variable, with shallow depths below 10 m prevailing. A particularly wide belt of shoals exists off the island of Uznam in the waters close to Świnoujście and around the island of Wolin. Farther to the east, between Wolin and Kołobrzeg, the 10-m isobath runs as close as one nautical mile from the shore. The coastline in this area, running from west-southwest to east-northeast, is rather smooth, and the isobath 50 m is not more distant than about 15 NM off the shore.

3 DEFINITION OF LOW SEA LEVEL

No obligatory definition of "low sea level" is in force in the hydrological forecasting and warning service and no obligatory warnings on expected occurrence of this phenomenon are issued. For this investigation the level 440 cm has been accepted for the southern coast of the Baltic Sea as the warning level for navigation, according to the NAVTEX.

4 LOW SEA LEVELS GENERATORS

Sea level changes along the coasts are generated by several factors, mainly by the wind impact on the sea surface and, to some extent, by the actual water volume of the sea. Most spectacular deformation of the water surface at the Baltic Sea shores can occur due to the already mentioned off- or on-shore, stormy, sometimes hurricane-like winds, veering or backing, accordingly to the weather system actually passing along or across the coast. The force of the wind against the water surface causes deformations which become the greater, the shallower is the area of the sea.

Of essential influence are however, the local conditions. In shallow areas, such as the Baltic Sea, the wind exerts dominating influence on the water level. The magnitude and the character of the sea level changes depends thus on the coast line configuration, on the exposition of particular coast part to the actual wind, on the bathymetry of the adjacent sea basin, the currents, etc. Sometimes, even in the same time the opposed water level tendencies can be observed along a comparatively short section of the same coast. The grounds for this differences lie mainly in the morphology and in the peculiar hydrographic character of this coast. In some cases, however, these opposed tendencies are due to a rapid changes of the storm direction within a limited area of the wind field.

5 METEOROLOGICAL INFLUENCES

Strong wind is the dominant factor, which forces the water surface oscillations in the Baltic Sea. An offshore wind depressing the water surface at the shore is usually less vehement over the land than on the sea, and, depending on the character of the coast line, can have more or less deflected direction. Much stronger effect than the wind measured at the shores exert the storms, which accompany the low pressure systems moving across the Baltic Sea, affecting considerable areas of water. A rather seldom, though noteworthy cause of low levels is a long lasting gale connected with an anticyclone over Scandinavia and Russia and influencing a vast area of the whole Baltic basin. Each of the mentioned wind systems, though transforming and very much influenced on their way, develops in accordance with the actual specific pressure pattern over Europe and the adjacent Atlantic Ocean.

The Norwegian and North Seas, the Scandinavia and the Baltic Sea, are situated in the west wind zone. They are an area over which the atmospheric disturbances, mostly active depressions with the fronts systems, move eastwards from over the Atlantic Ocean. In the fore field of a depression winds of a strong southern component prevail, behind the fronts usually veering. The winds in the fore field of a depression are offshore in relation to the southern coasts of the North and Baltic Seas. The depressions are common here.

Some depressions, on their way eastwards, when entering Scandinavia, slow down, though continue to deepen. The pressure gradient gets very steep and the initially stormy wind grows to hurricane force. At the southern coasts the offshore-wind-driven-level-decrease begins and holds on, until the wind calms, or veers. Typical reaction of the levels to such wind forcing is, at first, a gradual decrease along a big part of the coast, then, pretty often, a sharply accelerated sinking when the storm grows to maximum force and finally a prolonged minimum which lasts as long as the hurricane force hold on, without changing the direction. When the wind veers, the levels begin a more or less rapid increase (often supported by the now along or onshore wind).

Another type of low sea level variation can be observed when a strong, stationary anticyclone covers, or oscillates over the Fennoscandia and the northwestern parts of Russia. In such atmospheric situation two main factors strive to diminish the water levels. The first one is the considerably increased hydrostatic pressure in the powerful high. The other one is the wind system, which develops at the south-western outskirts of the high: over the northernmost areas of the Baltic Sea prevail light to moderate winds of a high northern component; going south the winds veer to easterly and south-easterly and grow in force, sometimes to storm in places. In the westernmost part of the Baltic Sea, in the Sound and in the south-east of the North Sea dominate the south-easterly and southerly winds. If such configuration of pressure systems persists for long enough – a week, two or even more, the surface water not only is pushed away from the shores, but is also forced out of the sea basin through the Belts and the Sound. All the coastal water gauges in the Baltic Sea (except, perhaps, those in the Sounds) should then record decreased levels.

6 SOME PARAMETERS OF THE DECREASING LEVELS

The process of sea level decrease begins, as already said, forced by the impact of a strong wind. Depending on the wind character, the decrease can be rapid and short lasting, or smooth and need a longer time to develope. The acting force (wind) can cover the whole area in the same time or, what is more frequent, can progress from west to east, only in rare cases – from east to west. Sometimes it can influence only a part of the coast. It must be also kept in mind that a decrease sea level is only a phase of the sea surface oscillation, followed (or preceded) by a rise of sea level – the other

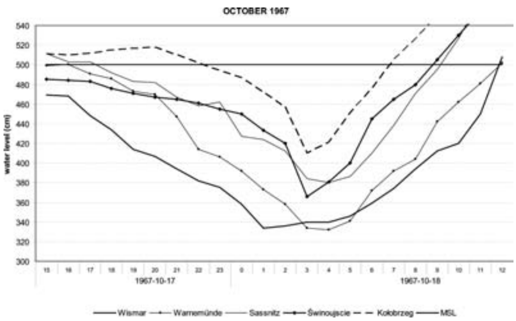

Figure 1. Fragment of sea level decrease during the storm on 17–19th Oct, 1967.

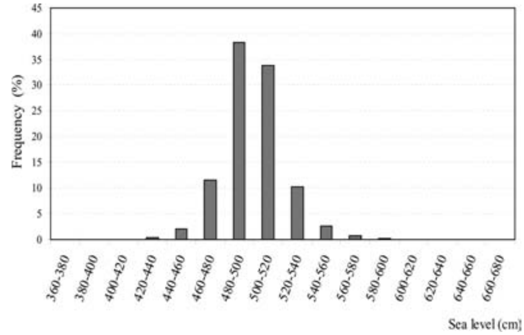

Figure 2. Frequency distribution of sea level values, Świnoujście, 1955–2005.

phase of this wind driven oscillation. An illustration of a sea level decrease can give the variation curves of the falling sea surface at the southwestern coast of the Baltic Sea.

In the afternoon and night of 17 October, a deep meteorological depression was almost stationary over the Kattegat and southern Sweden. A very strong westerly to southwesterly storm of 8–9 Bft, and of 10 Bft in places, developed over the eastern North Sea and the southwestern basins of the Baltic Sea. Behind the occluded front, the storm veered northwest in the early hours of 18 October, without calming during the next several hours.

On 17 October 1967, sea levels on the southwestern Baltic Sea coast oscillated slightly above the mean value. Around noon, they dropped first in the Wismar Bay, which is the area most sensitive to the impact of gale-force offshore winds. Water levels began to fall steadily, initially at a rate of about 10 cm/hour, later 10–15 cm/hour. A less regular rate of decrease was recorded at the other water level gauges. Kołobrzeg, the easternmost of the considered water gauges, was the last station to record falling water levels on this part of the coast. The values there remained above 500 cm until the westerly (alongshore) winds had backed SW, partly S, at about 21 UTC. This forced a rapid drop of sea levels in this area. Minimum levels were recorded just after midnight on 18 October, between 01 and 04 UTC. The storm however, still came from southerly directions, causing water levels to drop particularly rapidly (Fig. 1).

Rates of decrease were as high as about 40 cm/h in Sassnitz, and about 50 cm/h in Kołobrzeg and Świnoujście. The lowest minima were as follows: Warnemünde 332 cm, Wismar 334 cm, Świnoujście 362 cm, Sassnitz 381 cm, and Kołobrzeg 435 cm. During that storm levels below 440 cm remained for 17 hour in Wismar, while in Kołobrzeg only for 2 hours. The severity of the storm, which veered NW–N, caused the sea levels to start rise again, immediately at high rates, to compensate the difference of more than 1.5 m in 5–7 hours.

During a series of another three successive storms, between 29 November and 7 December 1999, one of them caused a particular deep sinking of the sea levels, particularly on 4 December. The intensity of the storm raging in the whole southwestern area of the Baltic Sea, from the Sounds to the coasts of Kołobrzeg, reached and at times exceeded 9 to 10 Bft. The highest rates of decrease oscillated about 25–15 cm/hour, while the absolute minima were as low as 309 cm in Wismar and 333 cm in Warnemünde. In Wismar the water stayed below 440 cm for 19 hours.

7 FREQUENCIES

Extremely low sea level values recorded along the southern coast of the Baltic were as high as 370 cm in Kołobrzeg (1979-11-04), 366 cm in Świnoujście (1967-10-18), 357 cm in Sassnitz (1939-12-22), 332 cm in Warnemünde (1967-10-18) and 309 cm in Wismar (1999-12-04).

In Świnoujście, for example, most frequent values of the levels were closest to the mean sea level, that means to H = 500 cm (Fig. 2). About 90% of the measured levels were included in the intervals between 520 cm to 480 cm only about 0,3% of the levels were lower than 440 cm and in the months from May to August such low values were not recorded at all. In the same years in Warnemünde the frequencies of particular sea level values were as follows: between 520 cm and 480 cm included were about 70% of the values. Only scarcely smaller than 1% were the levels below 440 cm.

In one month of the year namely in June no levels lower than 440 cm occurred.

8 LONG-TERM VARIATION OF LOW SEA LEVEL OCCURRENCES

The long-term variation of low sea level occurrence and annual frequency distribution provides important information on this hydrological effect.

Very low sea levels in the Baltic Sea occur very irregularly and are extremely rare in summer. At the declared low level limit of 440 cm they are a marginal phenomenon. At the southern coast their frequency

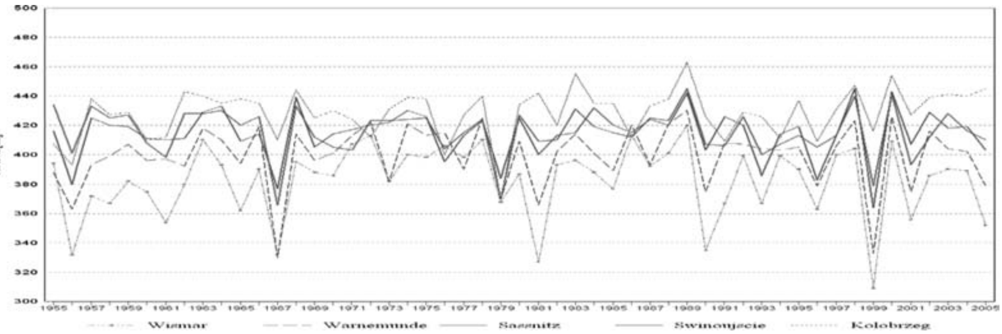

Figure 3. Long term variation of absolute annual sea level minima in Warnemünde, Wismar Sassnitz, Świnoujście and Kołobrzeg, 1955–2005.

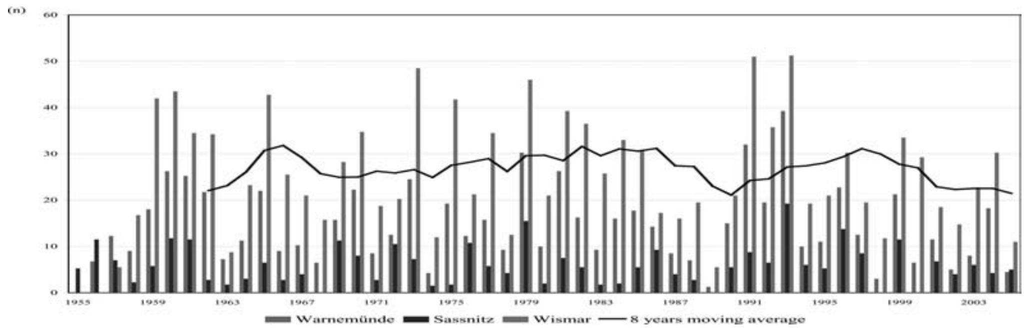

Figure 4a. Long term variation of low sea level events H ≤ 440 cm in Warnemünde, Sassnitz and Wismar, 1955–2005.

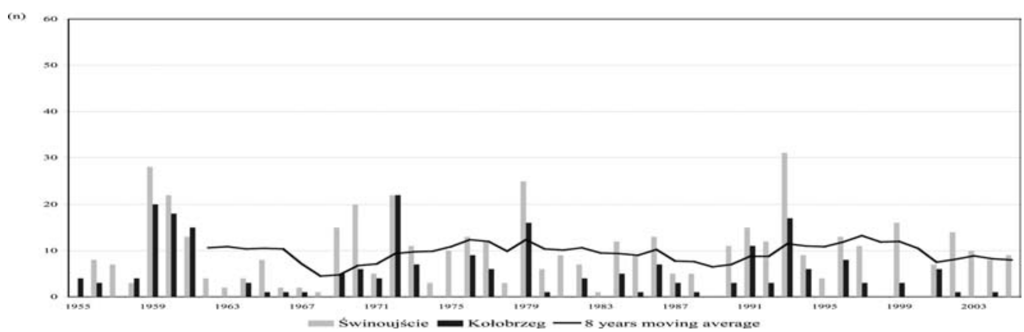

Figure 4b. Long term variation of low sea level events H ≤ 440 cm in Świnoujście, Kołobrzeg, 1955–2005.

and deviation of magnitude decrease, when moving east. For instance, while in Wismar and Warnemünde, in each of the years between 1955 and 2005 the values of absolute minima fell lower than 440 cm or even lower than 420 cm, so already in Sassnitz and Świnoujście they remained above the threshold value in three of these years (1989, 1998 and 2000), and in Kołobrzeg ten of the absolute annual minima in this 50 years stayed above 440 cm.

The range of variability of the absolute annual minima reached to about 1 m in those 50 years: in Wismar from 420 cm to 309 cm, in Warnemünde from 431 to 331 cm, in Sassnitz from 444 to 364 cm, in Świnoujście from 445 to 366 cm and in.

The 5 extremely deep minima of the time considered (1956, 1967, 1981, 1989, 1999) were the effect of the same hurricane like storms. So was also the case in the year 1979, when the decrease was exceptionally deep in Kołobrzeg, where the water fell nearly as low as in Wismar and Warnemünde, what usually is not the case (Fig. 3). Those events were due to very deep depressions with accompanying hurricane like winds, passing across the Baltic Sea.

The long term variability of low sea level (H ≤ 440) shows much more low levels occurrences in the western part of the coast than in the east. However, in some years low levels were not recorded at all, e.g. in 1989, 1998 in Sassnitz, Świnoujście, Kołobrzeg (Figs 4a, b).

Maximum number of low sea level events ($H \leq 440$) had the year 1993 in the whole southern cost, from Wismar to Kołobrzeg, similarly was in 1979 and 1959. The number of low level events varies from year to year, changing by as much as two or three times. In general an increase of low level events was observed at the turn of nineteen fifties to sixties, in the seventies to mid-eighties and also in the nineteen nineties. The behavior of the general low sea level variation is given in Figures 4a and 4b, by bars and by curves of 8 years moving averages, calculated for Wismar and Świnoujście.

9 PROBABILITY

The Gumbel method is well suitable for evaluating the probability of low sea levels. In Gumbel distribution, the extreme-value events are distributed asymmetrically.

The following probability of non-exceedance W(x) has been used as design basis for the occurrence of a low sea water event with the value x:

$$W(x) = e^{-e^{-y}}$$

and: $y = a(x - b)$
where: $W(x)$ = probability of non-exceedance; x = annual water level minima
from where it follows:

$$W(x) = e^{-e^{-a(x-b)}}$$

Probabilities according to the Gumbel method are computed by means of the above conditional equations using annual extreme water levels.

They are updated annually.

The recurrence intervals were calculated using the absolute annual sea level minima in Wismar, Warnemünde, Świnoujście and Kołobrzeg from the years 1955–2005 and the above mentioned Gumbel probability method. From the calculations it follows that, for instance every 50 years a sea level slightly below 330 cm would occur in Wismar, which in Kołobrzeg a 50 years value is as low as 390 cm.

A 20 years value in Wismar is as low as about 335 cm, while in Kołobrzeg is scarcely falls below 400 cm (Fig. 5). The probability of occurrence of low sea level on the southern coast decreases from west to east.

The percentile is a measure which gives information on the per cent of observations found below a definite value. Figure 6 shows the percentile distribution of monthly minimum sea levels for the southern coast of the Baltic Sea.

25th percentile (lower quartile) is the value, below which 25 percent of all observed water levels fall. In Wismar 25% of all values was below 367 cm, in Warnemünde below 392 cm, in Świnoujście below 407 cm and in Kołobrzeg below 414 cm. Upper quartile (75th percentile), often used in statistical characteristics, is the value of variable below which there is

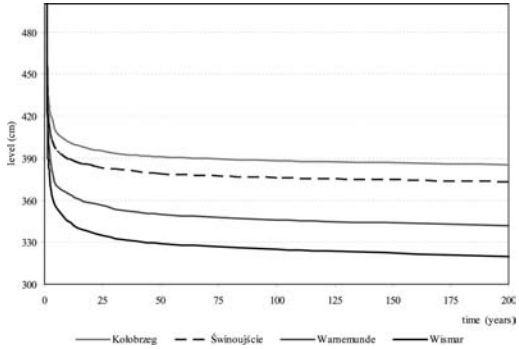

Figure 5. Low sea level as a function of statistical recurrence from 4 gauge stations, 1955–2005.

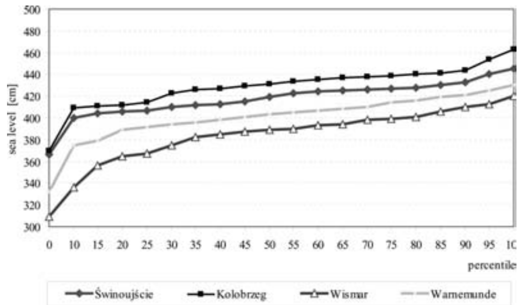

Figure 6. Percentile distribution of monthly lowest sea level at the 4 gauge stations.

75% of all analyzed values. In the case of all here considered stations, the maximum value of 75th percentile was 439 cm in Kołobrzeg and 427 cm in Świnoujście.

This means that in Świnoujście 75% of observations was below 427 cm. In Warnemünde 75% of observations of monthly lowest sea level was below 414 cm and below 399 cm in Wismar. The 50th percentile is an equivalent of the median. In case of the analysed stations the median amounts to: 431 cm in Kołobrzeg, 419 cm in Świnoujście, 403 cm in Warnemünde and 389 cm in Wismar.

10 CONCLUSIONS

Considered was the low sea level at the southern coast of the Baltic Sea as a factor influencing the navigation safety, the off shore engineering and in general the maritime management. The range of the actually met sea level oscillations may grow in face of the expected global warming.

Extreme values of the lowest sea level met in the presented paper, range from 309 cm in Wismar, in the western area, to 370 cm in Kołobrzeg – central part of the southern coast (that means 191 cm below the mean sea level and 131 cm below the NAVTEX warning level). Extreme rates of decrease can reach 50 cm/hour (or more).

Such conclusions point at the importance of the warnings against very low level. This would be a significant information when the under keel clearance could be critical.

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11.6
Measurement system for wind and waves characteristics registration on the Silm Lake

L. Morawski, J. Pomirski, P. Sikora & R. Sokół
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: This paper describes the system for registration of waves and wind disturbance. Ultrasonic anemometer measures wind parameters. Capacitor sensor is used for measurement of wave height. The wave sensor changes its capacitance according to the immersion of the sensor in water. The measurement system is controlled by the microprocessor system, which collects data from the sensors and retransmit them to the computer via radio modem. The system is used for design and simulation of control systems for isomorphic ship models on the Silm Lake near Ilawa, Poland.

1 INTRODUCTION

During precise control of ship movements at small velocities and when dynamic positioning task is performed, disturbance has considerable impact at the control accuracy. Particular influence to the ship movements are during trials on isomorphic ship models which are used for captains training and also for control systems research in the Ship Handling Research and Training Centre at Silm Lake near Ilawa, Poland. Most of isomorphic ship models have been built in the 1:24 linear scale. According to the laws of mechanical similarity during trials on the lake time run $\sqrt{24} \approx 5$ times faster than during operations on the real ship. The same scale $1{:}\sqrt{24} \approx 1{:}5$ must be used for comparison of velocities in the real world and on isomorphic ship models. Therefore even small wind disturbance during tests affects ship model like quite strong wind and wave disturbance acts the real ship (Szalangiewicz 1996; Morawski 2007).

To take into consideration the external disturbance in the control process the appropriate mathematical model of wind and wave disturbance is required. The model enables a design of more precise control systems and also more sophisticated computer simulations can be done. This paper describes design of the measurement system, which is used for collecting wind and wave parameters on the Silm Lake. The registered data will be base for development of mathematical models of disturbance on the lake.

2 MEASUREMENT SYSTEM DESIGN

The wind and waves measurement system diagram is given in figure 1. It consists of measurement sensors, which are installed on a dolphin fixed in the lake bottom in some distance form a lakeshore. The measurements are collected by a remote computer, which can be installed on a shore or on the ship model.

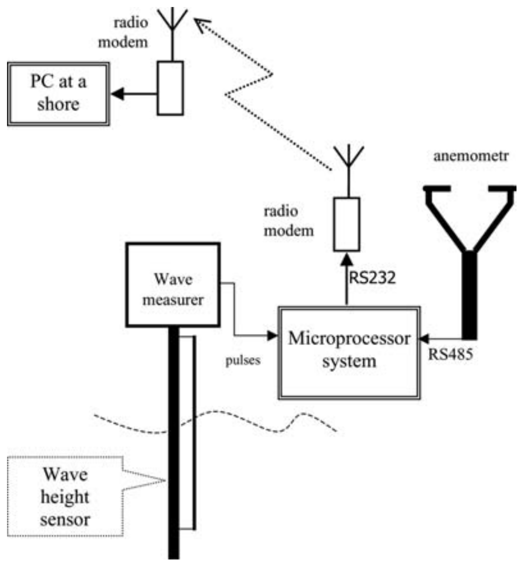

Figure 1. Wind and waves measurement system.

2.1 *Anemometer*

The ultrasonic anemometer measures the time taken for an ultrasonic pulse to travel from one transducer to the opposite transducer and then compares it with the time taken for another pulse to travel in the opposite direction (Fig. 2).

The speed c_{12} of the pulse travelling in the same direction as wind and opposite direction c_{21} are given by:

$$c_{12} = \frac{L}{T_1} = c + V_w$$
$$c_{21} = \frac{L}{T_2} = c - V_w \qquad (1)$$

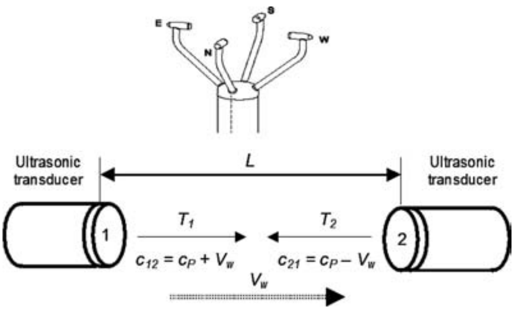

Figure 2. Ultrasonic wind speed measurement.

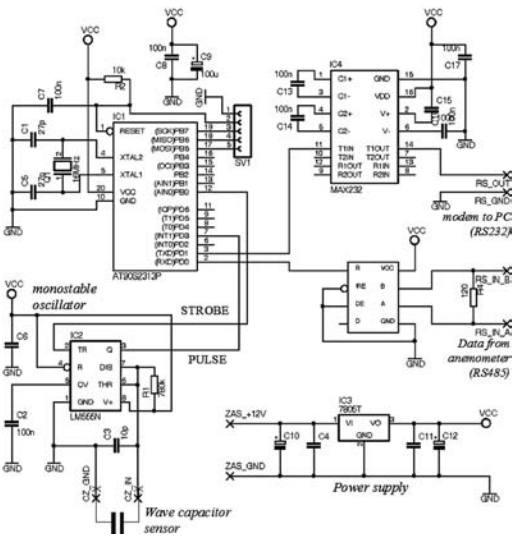

Figure 3. Electronic circuit of wind and waves meter.

where:

V_w – is a wind speed component, which is parallel to the 1–2 line,

c – is a speed of the sound in the air (it depends on air temperature),

L – is a distance between both transducers.

If both times T_1 and T_2 are known, it is possible to calculate wind speed V_w and speed of the sound in the air c:

$$V_w = \frac{L(T_2 - T_1)}{2T_1T_2} \qquad c = \frac{L(T_2 + T_1)}{2T_1T_2} \qquad (2)$$

Gill Instruments' WindObserver II has been used for the wind measurements. It has two pairs of ultrasonic transducers, which are used for calculation of two perpendicular components of the wind speed. Both components can be easy converted to the polar co-ordinates i.e. wind speed and direction. Both co-ordinates are calculated with 2% accuracy. The data are transmitted 10 times per second in the NMEA 0183 format through RS422 interface to the microprocessor system (WindObserverII User Manual).

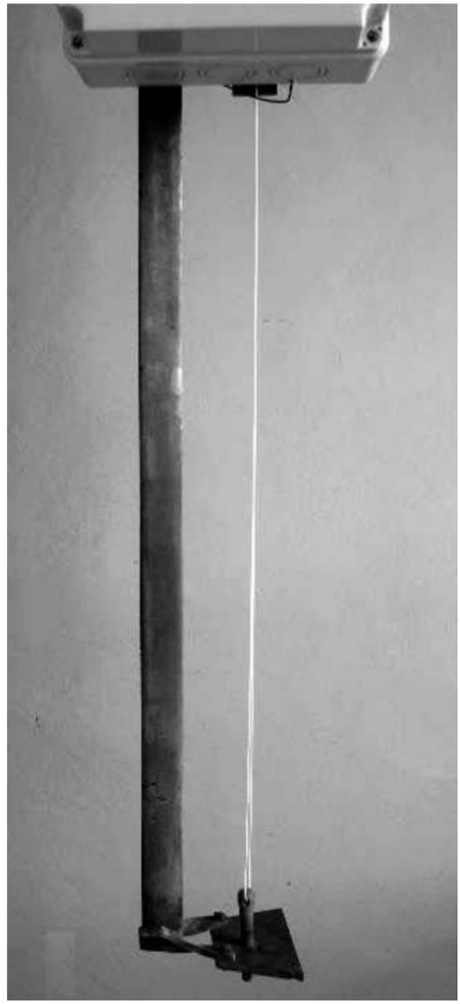

Figure 4. Wave sensor – capacitor partially immersed in the water.

2.2 *Wave height measurer*

Electronic part of the wave measurer (Fig. 3) consists of:

- a sensor, which capacitance changes due to immersion of the sensor in a water
- a monostable oscillator, which forms pulses according to the capacitance of the sensor,
- a transmission module which receives data from anemometer and sends data to the PC on a shore,
- a microcontroller which controls an operation of the measurer.

Capacitor sensor is used for measurement of wave height. It is formed by two electrodes (Fig. 4). The flat bar is one of electrodes. The bar is also the element of mechanical structure of the sensor. Second electrode is composed by the thin copper wire with a teflon isolation coat. The wire is parallel to the bar. The permittivity of the air and the water are different, so the capacitance of the wave sensor depends on the wave level as it causes what part of the sensor is under the water.

The sensor immersion in the range 0–500 mm corresponds to the capacitance variance from 40 pF to 400 pF. The capacitor is a part of the monostable oscillator composed by a popular LM555 chip (LM555 Data sheet). In this chip the time pulse width strictly depends on the connected capacitance. Pulse generation is strobbed by the microcontroller. The microcontroller also measures the pulse time width. The 32 partial measurements approximate final result. Measurement is available 10 times per second. Relationship between the pulse time width and the sensor immersion (the wave height) was determined by experiment. The damping of the electrodes by water mainly influences the measurement accuracy. Static error of wave height measurement is less then 1 mm, but maximum dynamic error is bigger – it was estimated to 5 mm.

Additional microcontroller tasks are collecting of the data from the anemometer and then retransmittion of both the wave and wind parameters to a computer through radio modem. Transmission baud rate of the radio modem is limited to the 4800B. Because the measurements are available every 100 ms (10 Hz), and the NMEA format of data received from anemometer causes long time of transmission (70 ms), and moreover 32 measurements of wave height are performed in parallel, therefore the microcontroller program has been quite difficult to write. Transmission of the data to the shore reduces power requirements for the measurement system, so the weight of the equipment installed on the lake is lower, therefore even thin dolphins, far away from a shore could be used for the measurer fixing.

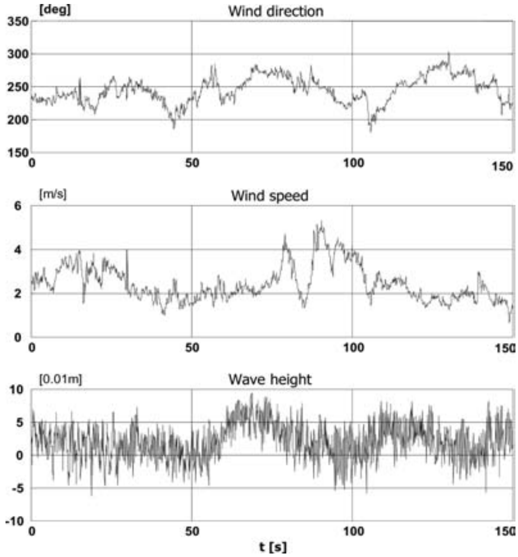

Figure 5. Direction and speed of wind and level of wave recorded on Silm lake.

Data are transmitted by radio modem, so the sensors are light enough to be mounted even on the thin beacon fixed to the lakebed. Another advantage of the measurer is small power consumption, therefore battery supply can be used to register data for many hours. The slow baudrate has been selected for transmission, it caused some problems in software design, but finally the cheap radio modem can be used, moreover an influence of the disturbances is reduced and the distance range covers nearly whole lake.

3 CONCLUSION

Examples of the wind and waves parameters was recorded on the lake and given in the figure 5.

The described measurement system enables registration of wind and waves parameters and finally it will be possible to construct of appropriate mathematical models of wind and waves disturbance which appears on the Silm Lake during trials on isomorphic ship models.

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11.7
Simplified method for estimating maximum ship's draught when navigating in shallow water on the south of Stolpe Bank in the aspect of the vessels with maximum dimensions and draught

G. Rutkowski & A. Królikowski
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: This paper considers analysis of maximum draught of a merchant vessel, which can maintain safety of navigation in different exterior condition (average and extreme) on shallow water in Stolpe gutter and keep required under keel clearance, i.e. navigational reserve of depth. To depict maximum draught of a vessel we use practical method which incorporates risk of navigational and model of ship's domain. Results are compared with guidelines published by Decree of Minister of Transport and Maritime Economy from 01.06.1998 about technical conditions, which should be met by hydro mechanical sea structure, which operate vessels with the given particulars.

1 SAFETY OF NAVIGATION IN STOLPE GUTTER

1.1 *Introduction*

This paper considers analysis of maximum draught of a merchant vessel, which can maintain safety of navigation in average and extreme exterior (weather) conditions in Stolpe gutter and keep required under keel clearance, i.e. navigational reserve of depth.

Analysis of navigational reserve of depth (under keel clearance) is made in different exterior condition (average and extreme) for merchant vessels such as:

- VLCC vessel or bulk carrier whose particulars are: LOA (length over all) L = 350,0 m, beam B = 60,0 m, draught in the Baltic Sea[1] $T_D = T_R = 15,00$ m, block coefficient $C_B = 0,85$.
- Container ship whose particulars are: LOA (length over all) L = 250,0 m, beam B = 32,0 m, draught $T_D = T_R = 12,00$ m, block coefficient $C_B = 0,70$.
- Passenger ferry whose particulars are: LOA (length over all) L = 140,0 m, beam B = 16,0 m, draught $T_D = T_R = 7,50$ m, block coefficient $C_B = 0,65$.
- Fishing boat whose particulars are: LOA (length over all) LOA = 40,0 m, beam B = 8,5 m, draught $T_D = T_R = 4,00$ m, block coefficient $C_B = 0,63$.

Results are compared with guidelines published by Decree of Minister of Transport and Maritime Economy from 01.06.1998 about technical conditions, which should be met by hydro mechanical sea structure, which operate vessels with the given particulars.

2 GUIDELINES OF POLISH MINISTER OF TRANSPORT AND MARITIME ECONOMY CONCERNING UNDER KEEL CLEARANCE

Let us consider the theoretical establishing of Separation Zone in the area of Stolpe gutter in accordance with guidelines published in the Decree of Polish Minister of Transport and Maritime Economy from 01.06.1998 (Dz.U.98.101.645) about technical conditions, which should be met by hydro mechanical sea structure and the location – Section II, Chapter 3, § 25 to § 35.

Every sea structure situated within Polish area description three depths of water:

- Designed depth H_p,
- Acceptable depth $H_{dop.}$
- Technical depth H_t,

Designed depth H_p is specified by formula:

$$H_p = H_t + t_b \tag{1}$$

where: H_p – designed depth, [m]; H_t – technical depth, [m]; t_b – dredge reserve tolerance, [m].

A value of tolerance for dredge reserve, accepted to estimate sea structures and design drawing works, with respect to the location of drawing works, is:

- $t_b = 0,25$ m – for drawing works made in port and harbours,

[1] Limitation of draught T = 15,0 m was accepted in Baltic Sea such as maximum for the vessel wanted to sail safe across Danish straits (Great Belt with Hn = 17,0 m). Since November 2007 according to the Notice to Marines limitation of ship's draught has been reduced to 14,50 m due to shallow water in Great Belt with depth Hn = 16,50 m.

– $t_b = 0{,}35$ m – for drawing works carried out outside limits of harbours, especially on the roads, in the approaching channels, for placing cables and pipelines in territorial sea and interior sea waters as well as profiling sea bed for sea's structures.

Every designed project includes specific width of sea bed lane along sea structure, in which one should keep acceptable depth ($H_{dop.}$). If the technical documentation, such as navigational chart, describes only one depth of the area, we assume that this depth constitutes acceptable depth ($H_{dop.}$). In this way technical depth (H_t) can be presented in meters on the basis of the following formula:

$$H_t = H_{dop.} - t_b \tag{2}$$

where: H_t – technical depth, [m]; H_{dop} – acceptable depth, [m]; t_b – full tolerance for dredge reserve, [m].

When we use navigational depth (H_n) we think about difference between horizontal planes, measured from average sea level SW to horizontal plane, which is adjoined with the highest bed situated in the given area, which is designed for vessel traffic.

Actual navigational depth (H_{na}) is navigational depth (H_n), which refers to actual water level.

Acceptable depth (draught) of the ship (T_a) in traffic areas describes difference between actual navigational depth ($H_{na\ a}$) and total under keel clearance (R_t) required in sailing condition:

$$T_a = H_{na} - R_t \tag{3}$$

where: T_a – acceptable ship's depth (draught), [m]; H_{na} – actual navigational depth, [m]; R_t – total under keel clearance depth, which enables the vessel to float in the place where sea structure is located, even for the unfavourable hydro meteorological conditions, [m].

The next link (4) shows relationship between the highest acceptable ship's depth (draught) (T_c) and technical depth (H_t):

$$H_t = T_c + R_t \tag{4}$$

where: T_C – is the highest ship's depth (draught) on even keel, [m]; R_t – total under keel clearance depth, which enables the vessel to float in the place where sea structure is located, even for the unfavourable hydro meteorological conditions [m].

Total under keel clearance, which is included in formulae (3) and (4), cannot be smaller than minimum of total reserve of water depth (R_t^{min}), described in meters by the following formula:

$$R_t^{min} \geq \eta \circ T_c \tag{5}$$

where: T_C – is maximum acceptable ship's depth (draught) on even keel, [m]; η – not dimensional coefficient, dependent on the type of area or fairway, described in Table 1.

In this case the minimum value of total reserve of water depth R_t^{min} established for different type of ships (unit) is described in Table 2.

Table 1. Values of not dimensional coefficient, with respect to type of area or fairway. Dz.U.98.101.645.

No	Type of area or fairway	η
1.	Harbour areas covered from waves	0,05
2.	Interior fairways, ship's rotary area, basin and port channel in which floating units use tugs	0,05
3.	Exterior approaching lane from sea to port and marina	0,10
4.	Open sea areas	0,15

Table 2. Minimum value of total reserve of water depth R_t^{min} established for different type of ships (units) in shallow water in Stolpe gutter.

No	Type of units (L,B,T, CB)	Tc [m]	R_t^{min} [m]
1.	VLCC (350 m; 60 m; 15 m; 0,85)	15,0	2,25
2.	Container ship (250 m; 32 m; 12 m; 0,70)	12,0	1,80
3.	Passenger's ferry (140 m; 16 m; 7,5 m; 0,65)	7,50	1,13
4.	Fishing boat (40 m; 8,5 m; 4 m; 0,63)	4,00	0,60

Assuming actual navigational depth area in average navigational conditions $H_{na} = 17{,}00$ m and ship's particulars of the biggest units which could enter to the Baltic Sea through the Danish Strait (Great Belt, $H_{na} = 17{,}00$ m, $T = 15{,}0$ m) minimum of under keel clearance should be not less than 2,25 m. In this case criterion of safety navigational depth cannot be used, because: $H_t = 17{,}0$ m–$2{,}25$ m $= 14{,}75$ m and is smaller than maximum unit's draught $T_a = 15{,}0$ m.

In extreme conditions, such as huge wave, situation can be worse, as one should reduce navigational depth of the area to $H_{n1} = 16{,}50$ m and increase the maximum of ship's draught T_a due to wave effect: yawing, pitching, rolling etc. For example mere list of about $\pm 5°$ of the rolling vessel whose beam $B = 60$ m and departure draught $T_{a0} = 15{,}0$ m, can increase maximum of ship's draught for 2,56 m to $T_{a1} = 17{,}56$ m.

The increase of the ship's draught, which is caused by the list, can be depicted by means of the following formula:

$$\Delta T_7^{II} = T_M\left[\cos(\theta) - 1\right] + \frac{1}{2} \cdot B \cdot \sin(\theta) \tag{6}$$

where: ΔT_7^{II} – change of draught in case of ship's list [m]; T_M – average ship's draught [m]; θ – angle of ship's list [°]; B – ship's beam [m].

The increase in the ship's draught, which is caused by yawing, can be calculated by means of the formula:

$$\Delta T_7^{I} = \frac{1}{2} \cdot L_w \cdot tg(\Psi) \approx \frac{1}{2} \cdot L_{pp} \cdot tg(\Psi) \tag{7}$$

where: ΔT_7^{I} – change of draught in case of yawing [m]; L_W – ship's length on sea surface [m]; L_{pp} – ship's length between perpendiculars [m]; Ψ – angle of trim due to yawing [°].

In bad weather conditions one can observe heaving, yawing, pitching, rolling, swaying and surging due to huge influence of sea wave to ship's hull. In practice in order to define maximum ship's draught one uses only bigger value of corrections ΔT_7^{I} or ΔT_7^{II} defined by the formulas (6) and (7).

For this reason, on the basis of formulas (4) and (5) one can define simplified formula for maximum acceptable ship's draught Tc, which could indicate safe navigation in area with technical depth H_t:

$$T_c \le \frac{H_t}{1+\eta} \tag{8}$$

where: T_C – is maximum acceptable ship's draught, on the even keel, [m]; η – not dimensional coefficient, dependent on type of area or fairway, described in table 1; $H_{t.}$ – technical depth, [m].

According to formula (8) in order to navigate safely near the Stolpe gutter (open area) the highest acceptable ship's draught T_c, should not be higher than $T_{c1} = 14{,}78$ m for $H_t = 17{,}0$ m (average conditions) and $T_{c1} = 14{,}35$ m for $H_t = 16{,}5$ m (rough sea).

When planning separation zone area on the south of the Stolpe Bank, minimum of water depth read from navigational chart (chart 252, INT1219) is 18 m estimated with reference to chart datum with respect to MSL (Mean Sea Level). According to the formula (2) this depth should be treated as acceptable depth of area (H_{dop}) with error for so-called acceptable unevenness of sea bottom. For open sea areas, such as Stolpe gutter, in which sea bed isn't durably strengthened, acceptable sea depth H_{dop} could be described by formula:

$$H_{dop.} = H_t + R_p \tag{9}$$

where: H_{dop} – acceptable draught of sea structures, [m]; H_t – technical depth of sea structures, described with accordance to the rules mentioned above; R_p – reserve for acceptable unevenness of sea bottom in the area, where sea bed isn't durably strengthen, during the whole period when the sea structure is used.

According to the Decree of Minister of Transport and Maritime Economy value of reserve for acceptable unevenness of sea bottom shouldn't be less than $R_p = 1{,}0$ m. For the sea structures without durable strengthening and for sea structures located in the following areas:

- on bend and outlet of river and strait to the sea,
- on narrowing river bed,
- with huge wave or significant stream of water near the sea bed, the value of reserve R_p cannot be less than 1,5 m.

Hence, with respect to the formulae (3), (4) and (6) we assume the value of navigational depth of area as $H_{n1} = 17{,}0$ m in normal navigational conditions (18,0 m–1,0 m = 17,0 m), and $H_{n2} = 16{,}5$ m (18,0 m–1,5 m = 17,0 m) for extreme conditions, i.e. huge wave or strong stream of water near sea bottom.

The research about the real value of navigational depth of the given area is confirmed by the opinion from employers of Maritime Office in Gdynia. The depth of the discussed area depth was controlled by employers of Maritime Office in Gdynia in 2007. They confirmed the localization of the navigational dangers such as rock, sand, wrecks within shallow water on the depth from 17,00 m with respect to actual sea level, the possible inaccuracy being ±0,50 m.

Polish sea areas are treated as sea without tides. Water depth is measured on these areas from chart datum, which is defined from average sea level SW (±0,50 m). According to long term observation made by Institute of Meteorology and Water Management in Gdynia in the area which we discuss one can expect significant changes of sea level in the aspect of mean sea level (MSL = 500). Those changes cross the value $\Delta Hn = Rp = \pm 1$ m. They are especially visible in autumn–winter term. For example in 2001 difference between extreme values of high sea water level (HHW) and low water (LLW) on the Polish coast varied from 146 cm in Ustka, 150 cm in Łeba to 206 cm in Świnoujście (Institute of Meteorology and Water Management, 2004).

In long-term scale (between 1971–2000) one can observe high water (HW) 130 higher than mean sea level (MSL) in Ustka and 140 cm in Łeba and low water (LW) about 54 cm lower than mean sea level (MSL) in Łeba and 60 cm in Ustka.

Total reserve of ship's draught R_t should be analyzed for every vessel navigating in this area. In every case total reserve of ship's draught R_t should not be less than minimum of total reserve of sea depth R_t^{min} defined earlier. Additionally, the reserve of ship's draught R_t should enable navigation and manoeuvring of a ship in the worst hydro-meteorological conditions, possible in this area.

According to the Decree of Minister of Transport and Maritime Economy from 1998 in order to establish the total reserve draught R_t one must consider the total of following components:

2.1 *Reserve R_1 for inaccurate hydrographical measurement of water depth.*

The value of reserve R_1 depends on the area's depth. Depth in navigational charts is presented with accordance to the defined standard of accuracy. International Hydrographic Organization IHO (Joseph, 1991) accepted the following standard (P = 95,4%) in 1987:

0,52 m for $H = (0 \div 30)$m;
1,72 % h for $H > 30$ m.

Since January 1991 in the British Admiralty charts (BA) the accuracy of data has been defined with measurement depth error (P = 95,4%) and has the value:

$$2 \cdot \delta_H = \sqrt{0{,}5^2 + (0{,}009 \cdot H)^2} \ \text{[m]} \tag{10}$$

Hence, the error equals about 0,53 m for the area of Stolpe gutter whose average depth is about 20 m.

Table 3. Reserve R_1 for hydrographical measurement error of water depth (sound error). Gucma, Jagniszczak, 1997.

	Area's Depth H [m]	Water Reserve R1 [m]
1.	do 4	0.10
2.	4–10	1015
3.	10–20	0.20
4.	20–100	0.01H

Charts published by local maritime administration (other than British) may have different standard accuracy due to local legal regulations. According to S.Gucma and I.Jagniszczak (1997) navigational reserve R_1 for area whose depth is 20 m should be about 0,20 m in practice.

We do not make mistake if we accept for further research 0.35 m as average value of reserve R_1 for hydrographical error of measurement of water depth.

2.2 *Navigational reserve R_2, is minimum of under keel clearance units, which is sufficient to floating, and depends on type of sea bed or method of sea bed fortification near sea structure*

Navigation reserve R_2 results from the fact that we do not know the exact sea depth, sea bed clearance, interpolation error between sounding or result of the hull contact with sea bed. In practice, the value of reserve R_2 ranges from 1,00 m to 1,50 m for not coastal areas, which are exposed to huge wave and currents near the sandy and rocky sea bed with low density of sounding. In the area of Stolpe gutter sea bed is tough and sandy with many rocks and stones.

2.3 *Reserve R_3 for low level of sea waters, defined on the basis of: a) curve of total time of stay water level, with respect to the measurements on sea water level patch, which are based on long term research, when the water level remained on the higher level during about 99% of time during research period or b) differences between sea level SW and sea level SNW,*

Navigational reserve R_3 is the result of observation of difference of sea level with reference to chart datum which is caused by specific hydro-meteorological conditions. Long lasting and strong wind which blows in land direction as well as flooding on the river increase the water level. Strong winds blowing from the land and low water state on the river decrease this level.

In practice, navigational reserve R_3 in such areas as in the Stolpe gutter without tides on South Baltic Sea, navigational reserve R_3 can reach 0,30 m. Anyway, we must remember that long term observations of water state in this area carried out by measurement stations in Ustka and Łeba confirm higher, that is about 0,60 m reduction of water state from mean sea level (MSL). Those observations are also kept the whole year (Institute of Meteorology and Water Management, 2004). In extreme weather (hydro-meteorological) conditions value of navigational reserve R_3 should be increased to 0,60 m.

2.4 *Reserve R_4 for shallow water in the area, which enables full exploitation of area in period between dredging and bottom cleaning operation*

In the area which we discuss there is no dredging or bottom cleaning operation. Sea Bed is formed naturally, so we can omit the value of navigational reserve R_4 for future considerations.

2.5 *Reserve R_5 for wave and swell,*

In order to estimate value of parameter R_5 concerning sea wave we use the methods which are approximated, and show us only outline of the real situation.

In order to describe difference of draught ΔT_5 for sluggish vessel on wave we often use empirical formula prepared by Dand and Ferguson (1973) and recommended by Nowicki (1999) – Method 1:

$$\Delta T_5 = k \cdot h_f \ \text{[m]} \tag{11}$$

where: k – coefficient depending on the relation between beam and length of ship with respect to length and course angle of the wave, the coefficient ranges from 0,33 to 0,66; h_f – height of wave [m].

Coefficient k depends on relation between beam and length of ship with respect to length and course angle of wave. In case of the ship, which is situated board to wave and whose beam constitutes less than half length of wave, the coefficient is the biggest one. For huge vessels in relation to size of wave this coefficient has minimum value. The following rules apply to the huge vessels:

- Sea wave direction is equal to the ship's heading line ($q \approx 000°$ or $180°$) and length of the vessel is bigger than length of the wave ($L \geq \lambda$);
- Sea wave direction is perpendicular to ship's heading line ($q \approx 090°$) and ship's width is bigger than half length of sea wave ($B \geq 0{,}5\lambda$);

where: λ – wave length [m]; B – ship's beam [m]; L – ship's length [m].

When the vessel is on the way the value of reserve must be increased (Jurdzinski, 1998) with respect to the vessel speed:

- 12,5% when speed $v \leq 10$ knots;
- 25,0% when speed $v > 10$ knots.

The next method which enables us to count vertical parameter of navigational reserve for the vessel on the wave is the method of L.E. van Houten (Nowicki, 1999) – Method 2. However, this method is limited to the vessels whose size ranges from 15000DWT to 65000 DWT. In case of vessels smaller than 15 000 DWT this method can be misleading and inaccurate due to mistakes concerning amplitude of waves for vessels on the way.

Table 4. Numerical value of coefficient m dependent on the ship's particulars (v, B, L, C_B) and wave parameters (λ, h_f, q).

m	For the wave from bow or aft (q ≈ 000° or 180°)	For the wave from board (q ≈ 090°)
0,500	When: $v = 0$, and $L > \lambda$	When: $v = 0$, and $B > \lambda$
1,000	When: $v \geq 10$ w, and $L \geq \lambda$	When: $v \geq 10$ w, and $B \geq 0{,}5 \cdot \lambda$
1,125	When: $v < 10$ w, and $L < 0{,}5 \cdot \lambda$	When: $v < 10$ w, and $B < 0{,}5 \cdot \lambda$
$\geq 1{,}250$	When: $v \geq 10$ w, and $L < 0{,}5 \cdot \lambda$	When: $v \geq 10$ w, and $B < 0{,}5 \cdot \lambda$

From the point of view of safety of navigation we could consider the additional element with respect to formula (11). The case of navigating obliquely to wave direction is presented in table as the value of total difference under keel clearance on the bow and aft, amidships and height of bow and aft part of the vessel. Parameter R_5 is: either $\delta_p(\Delta Z)_5$, that is the error which results from defining the change, or change in draught $\Delta Z_5 = \Delta T_5$ increased by error

$$\delta_p(\Delta Z)_5 : R_5 = \Delta T_5 + \delta_p(\Delta Z)_5 \text{ [m]} \tag{12}$$

In real conditions vessel on the wave makes very complicated movement, which is combination of simple movement in one direction. Usually one type of movement results in another. These two types mutually interact, as it is in the case of scenting which is in fact combination of heaving and rolling. In case of ship's movement on the wave the prognosis of changes in complex movement is based on usual accumulation of results. On the other side, additional increase of safety contour, especially in very bad weather condition, has positive influence on reducing risk of navigation, and increasing safety of navigation. For example, according to "Report of Working Group IV of the Pianc International Commission for The Reception of Large Ships", for traffic lane exposed to huge swelling minimum of the under keel clearance must constitute 15% of maximum ship's draught (Method 3).

Similar solution is described by Gucma and Jagniszczak, (1997), in which minimum reserve for wave in the open sea area on the straightforward traffic lane without dredgering, with sea wave height up to 3,0 m is assumed as 40% of maximum ship's draught (Method 4).

Rutkowski (2000) gives us another solution for reserve R_5 (Method 5):

$$R_5 = 0{,}66 \cdot m \cdot h_f \tag{13}$$

where: R_5 – reserve for wave [m]; h_f - height wave [m]; m – numeral coefficient (factor), dependent on ship's particulars (v, B, L, C_B) and parameters of wave (λ, h_f, q).

Exemplary values of navigational depth reserve R_5 for wave estimated by means of the above methods for different type of ships on shallow water in Stolpe gutter are presented in Table 5. The calculation considers various methods for the vehicles proceeding with 10 knots speed along traffic lane straight to wave with height 3,0 m and length 150 m in the open sea area, exposed to sea waves and current, with no dredging requirement.

Table 5. Hypothetical value of navigation depth reserve R_5 for wave calculated with the above described methods for different type of ships for shallow water in Stolpe gutter. In calculation we assume that every unit sails along traffic lane with 10 knots speed straight to wave whose height is 3,0 m and length 150 m.

Type of Vessel (L; B; T; C_B)	Value of reserve R_5 [m] for wave calculated with different methods				
	1	2	3	4	5
VLCC (350 m; 60 m; 15 m; 0,85)	1,00	3,15	2,25	6,00	1,98
Container ship (250 m; 32 m; 12 m; 0,70)	1,50	2,52	1,80	4,80	1,98
Passenger ferry (140 m; 16 m; 7,5 m; 0,65)	2,00	1,58	1,13	3,00	2,23
Fishing boat (40 m; 8,5 m; 4 m; 0,63)	2,00	0,84	0,60	1,60	2,48

Due to big discrepancy of results we use the data from method 5 for further research. This method assumes that the reserve R_5 depends on the wave parameters and gives us result similar to methods 1,3 and 4. Methods 2 and 4 are very general and do not include interaction between ship's particulars and wave's parameters.

Long term observation of waves near Polish coast in area of Stolpe gutter in south part of Baltic Sea confirms that period with high frequency of storm and gale appears in winter time between November and February. In this period one can observe sea waves with height of about 3 m. Sea appears to be calm in summer time from May to September. Maximum of wind speed in the given area is up to 32 m/s. The maximum values of wave height are observed in winter time and they are up to 7 m in western part of Polish coast and up to 8m in eastern part of Polish coast. Maximum waves are observed during the strong and long-lasting winds from W, N and NE. The maximum waves amount to 160 m of length in eastern coast and about 120 m length in western coast. Predominantly the frequent waves are up to 3,0 m high and 40 m long. More than 90,85% of all waves in the area near the eastern coast and about 96,53% of all waves in area near the western coast are the waves whose height $H_{5\%}$ equals or is less than 1,5 m. Maximum sea waves whose heights $H_{5\%}$ reach more than 3,00 m are hardly ever observed. The probability that we can expect extreme weather condition

Table 6. The frequency of wave height in % on the South Baltic Sea. Paszkiewicz, 1989.

Wave's height $H_{5\%}$[m]	Eastern part of coast	Western part of coast
$H_{5\%} < 1,0$ m	75,26	88,64
1,0 m – 1,5 m	15,59	7,89
1,5 m – 3,0 m	8,85	3,46
$H_{5\%} > 3,0$ m	0,30	0,01

Table 7. The value of reserve R_6 for increasing ship's draught in breaking sea water near Polish coast on the Baltic Sea established by means of the formula 14 for different types of vessel.

No.	Type of ship (L; B; T; C_B)	R_6 [m]
1.	VLCC (350 m; 60 m; 15 m; 0,85)	0,38
2.	Container Ship (250 m;32 m;12 m;0,70)	0,30
3.	Passenger Ferry (140 m;16 m;7,5 m;0,65)	0,19
4.	Fishing Boat (40 m;B = 8,5 m;4 m; 0,63)	0,10

($H_{5\%} > 3{,}00$ m) in researched area is less than 0,3% in eastern coast and less than 0,01% in western coast.

2.6 *Reserve R_6 for the increasing ship draught when manoeuvring in breaking waters near the Polish coast on Baltic Sea established by means of the formula:*

$$R_6 = 0{,}025 \text{ x } T_c \tag{14}$$

where: T_C – the maximum draught of the vessel loaded on even keen, [m].

The reserve R_6 applies to all vessels proceeding to the Baltic Sea from the North Sea. This reserve concerns the increase off the ship's draught when manoeuvring in water near Polish coast. The density of sea water in Baltic sea equals from $\gamma_1 = 1{,}00525$ g/cm^3 to $\gamma_2 = 1{,}00250$ g/cm^3 what with relation to density of sea water in the North Sea ($\gamma_3 = 1{,}025$ g/cm^3) can increase the draught of each vessel which enters the Baltic Sea from the North Sea.

For the example the value of reserve R_6 estimated by means of the formula (14) for different type of the vessel are presented in Table 7.

2.7 *Reserve R_7, depicted in meters, for trim (pitch) up to 2° and list (roll) up to 5° established for all floating units by means of the following formulas:*

1 reserve for trim due to pitch up to 2°:

$$R^{I}_7 = 0{,}0016 \odot L_c \tag{15}$$

where: L_c– ship's overall length, [m].

2 reserve for list (roll) up to 5°:

$$R^{II}_7 = 0{,}008 \odot B_c \tag{16}$$

where: B_c – maximum ship's beam, [m].

In order to examine the depth of water we assume that the biggest value of reserve R_7 is bigger than two values a) and b) but not smaller than $R_7 = 0{,}15$ m.

The value of reserve R_7 can be estimated also by means of the formulas (6) and (7).

2.8 *Reserve R_8 for trim to aft for all vessels proceeding with speed over ground when dredging channels, approaching fairways, proceeding in interior fairways and channels, basin and port waters*

In this case as the area which we are discussing is the open sea with natural sea bottom the value of reserve R_8 can be ignored.

2.9 *Reserve R_9 for ship's squat when proceeding in restricted sea area across the shallow water*

When studying professional publications there are many methods for estimating reserve R_9 for ship's squat when proceeding in restricted sea area across the shallow water. In practice we can use only one of the following methods:

1 C.B.Barrass precise method for estimating ship's squat in sea area (Method 1) (with limitation: $0{,}5 \leq C_B \leq 0{,}9$; $0 \leq t/L \leq 0{,}005$; $1{,}1 \leq h/T \leq 1{,}4$):

$$R_9 = \frac{1}{30} \cdot C_B \cdot \left(\frac{BT}{bH - BT}\right)^{\frac{2}{3}} \cdot v^{2{,}08} \text{ [m]} \tag{17}$$

2 C.B.Barrass simplified method (Method 2) for estimating ship's squat in:

– shallow water (with limitation: $1{,}1 \leq h/T \leq 1{,}2$):

$$R_9 = 0{,}01 \cdot C_B \cdot v^2 \text{ [m]} \tag{18}$$

– narrow channel (with limitation:

$0{,}06 \leq \frac{B \cdot T}{b \cdot h} \leq 0{,}3$):

$$R_9 = 0{,}02 \cdot C_B \cdot v^2 \text{ [m]} \tag{19}$$

3 N.E.Eryuzlu and R.Hausser method for estimating ship's squat in sea area (Method 3)

$$R_9 = 0{,}113 \cdot B \cdot \left(\frac{h}{T}\right)^{-0{,}27} \cdot \left(\frac{0{,}514 \cdot v}{\sqrt{g \cdot H}}\right)^{1{,}8} \text{ [m]} \tag{20}$$

(with limitation: $C_B \geq 0{,}7$; $1{,}08 \leq \frac{h}{T} \leq 2{,}78$)

4 G.I.Soukhomela and V.M.Zass method for estimating ship's squat in shallow unrestricted water (Method 4):

$$R_9 = l \cdot \left[0{,}049047542 \cdot v^2 \cdot \sqrt{\frac{T}{H}} \cdot \left(\frac{L}{B}\right)^{-1{,}11}\right] \text{ [m]} \tag{21}$$

(with limitation: $3{,}5 \leq \frac{L}{B} \leq 9$)

where: B,L,T_{max}, C_B – ship's particulars: beam B[m], length L[m], maximum draught T[m], block coefficient C_B [-]; v- speed over ground in knots, [kn]; b,H,h_f - area characteristics: depth H[m], wide

Table 8. Relation between numeral coefficient (factor) l from formula (21), ship's length L and ship's beam B.

Value of numeral coefficient (factor) l dependent on ship's length L and ship's beam B		
$7 \leq \frac{L}{B} \leq 9$	$5 \leq \frac{L}{B} < 7$	$3{,}5 \leq \frac{L}{B} < 5$
1,10	1,25	1,50

Table 9. The value of ship's squat (reserve R_9) estimated by means of formula 17 to 21 (Method 1,2,3 and 4) for different types of vessel proceeding with 5 kn and 10 kn speed in shallow water with depth Hn = 17,0 m and wide b = 1000 m.

Method	Method 1		Method 2		Method 2		Method 4	
Speed [kn]	5	10	5	10	5	10	5	10
Ship's type	The value of ship's squat (reserve R_9) [m]							
VLCC	0,12	0,50	0,21	0,85	0,36	1,25	0,20	0,81
Container	0,05	0,23		0,18	0,63		0,12	0,46
Passenger							0,08	0,32
Fishing Boat							0,16	0,64

b [m], wave's height (swell) [m]; l- numeral coefficient (factor) ($1{,}1 \leq l \leq 1{,}5$) dependent on ship's length L and ship's beam B, [-].

Ship's squat (reserve R_9), estimated for vessel proceeding with 5knots speed and 10 knots speed in shallow water whose depth Hn = 17,0 m and minimum width b = 1000 m is presented in Table 9.

To sum up, navigational reserve of depth R_t described as a sum off all parts from R_1 to R_9 estimated for shallow water in Stolpe gutter should be dependent on size and type of a ship and actual weather condition; in Stolpe area the value should range from 4,61 m to 5,57 m.

In this case the highest acceptable ship's draught T_c (see Table 10), which could guarantee safe navigation near the Stolpe gutter with maximum swell and wave's height about $h_f = 3$ m and length about $\lambda = 150$ m, should not exceed the value $T_{c1} = 12{,}43$ m in bad weather condition for VLCC when proceeding with 5 knots speed and $T_{c2} = 13{,}39$ m in normal weather condition for Passenger Ferry when proceeding with 10 knots speed. Otherwise, the Decree of Minister of Transport and Maritime Economy will be not accepted.

What is more, in extreme weather conditions, such as winter time, wave (swell) which equals about $h_f = 5$ m and whose length is about $\lambda = 160$ m) one can expect higher value of navigational reserve of depth Rt, that is to say about 1,32 m.

Probability that we can expect extreme weather condition ($H_{5\%} > 3{,}00$ m) in this area, i.e. S of Stolpe Bank is less than 0,3% (See Tables 6 and 11). Extreme

Table 10. Maximum ship's draught Tc in shallow water estimated by means of formula (4) and navigational reserve of depth Rt as a sum of all parts from R_1 to R_9 in normal and bad weather condition ($h_f = 3$ m, $\lambda = 150$ m, $H_N = 18{,}00$ m) estimated for different type of vessel proceeding with speed 10 kn and 5 kn.

Good weather condition, Ship's speed 10 knots							
Ship's type	$R_{1\div4}$ [m]	R_5 [m]	R_6 [m]	R_7 [m]	$R_{8\div9}$ [m]	R_t [m]	Tc [m]
VLCC	1,75	1,98	0,38	0,56	0,81	5,38	12,62
Container vessel	1,75	1,98	0,30	0,40	0,46	4,79	13,21
Passenger Ferry	1,75	2,23	0,19	0,22	0,32	4,61	13,39
Fishing Boat	1,75	2,48	0,10	0,15	0,64	5,02	12,98
Bad weather condition, Ship's speed 5 knots							
Ship's type	$R_{1\div4}$ [m]	R_5 [m]	R_6 [m]	R_7 [m]	$R_{8\div9}$ [m]	R_t [m]	Tc [m]
VLCC	2,45	1,98	0,38	0,56	0,20	5,57	12,43
Container vessel	2,45	1,98	0,30	0,40	0,12	5,25	12,75
Passenger Ferry	2,45	2,23	0,19	0,22	0,08	5,17	12,83
Fishing Boat	2,45	2,48	0,10	0,15	0,16	5,34	12,66

Table 11. Maximum ship's draught Tc in shallow water estimated by means of a sum of all parts of the navigational reserve of depth Rt from R_1 to R_9 in extreme weather conditions ($h_f = 5$ m, $\lambda = 160$ m, $H_N = 18{,}00$ m.

Extreme weather conditions. Ship's speed 5 knots							
Ship's type	$R_{1\div4}$ [m]	R_5 [m]	R_6 [m]	R_7 [m]	$R_{8\div9}$ [m]	R_t [m]	Tc [m]
VLCC	2,45	3,30	0,38	0,56	0,20	6,89	11,11
Container vessel	2,45	3,30	0,30	0,40	0,12	6,57	11,43
Passenger Ferry	2,45	3,71	0,19	0,22	0,08	6,65	11,35
Fishing Boat	2,45	4,13	0,10	0,15	0,16	6,99	11,01

weather conditions can be expected only during winter from November to February with strong and long-lasting winds from W and NE.

3 SIMPLIFIED METHOD FOR ESTIMATING MAXIMUM SHIP'S DRAUGHT WHEN NAVIGATING IN SHALLOW WATER BY MEANS OF THE MODEL OF THE SHIP'S DOMAIN.

In this chapter we present methods that can be used for estimating maximum ship draught of a vessel. One

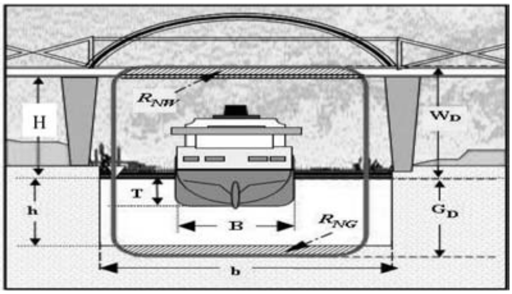

Figure 1. Presentation of navigational risk for ship passing shallow water and bridge.

must take into consideration safety of navigation, i.e. navigational risk in the restricted sea areas by means of the model of the ship's domain.

According to the ship's domain (Rutkowski, 2002) definition, every ship will be safe (in navigational meaning) as long as she is the exclusive object which can generate danger within her domain.

With reference to vertical plane of the three dimensional co-ordinates established down from the central point of the local ship's reference system we can affirm unambiguously, that every ship will remain safe as long the value of G_D is smaller than the real value of the sea depth H. Therefore, component R_{NG} of R_N can be referred to as vertical component of navigational risk that concerns keeping under keel clearance, or risk concerning under keel clearance. The component mentioned above can be depicted by means of the following formulas:

$$R_{NG} = \begin{cases} 0 & \text{when} \quad H \geq G_D \\ 0 \div 1 & \text{when} \quad T_{\max} < H \leq G_D \\ 1 & \text{when} \quad H \leq T_{\max} \end{cases} \text{[-]} \qquad (22)$$

According to the formula (22), assumption $H \geq G_D$ can be defined as the guarantee of the safe shipping (navigation) with reference to all underwater objects or obstructions immersed on the depth smaller than H. If sea depth H is smaller or equal to the ship's draught T, that is $H \leq T_{\max}$, according to the formula (22) sea passage can be unfeasible[2] or highly risky. In that situation the value of navigational risk R_{NG} will equal one, and in all probability it will signify unquestionable (100%) risk of collision with some underwater objects immersed on the depth less than H. Furthermore, we can also say that the value of navigational risk R_{NG} for the sea depth h limited between T_{max} and G_D ($T_{max} < H \leq G_D$) will be limited between zero and one ($R_{NG} \in [0,1]$) (see formula (22) middle line). General formula, which can be used to estimate navigational risk R_{NG}, depending on H factor from the range ($T_{\max} < H \leq G_D$), is presented below:

$$R_{NG} = \frac{G_D - H}{G_D - T_{\max}} \text{ [-]} \qquad (23)$$

[2] In our analyses we exclude the situation, when the ship can change her draught due to for example deballasting operation.

Additionally when we not only accept Barrass method, recommended by shipyards and ship's owners for estimating ship's squat, but also take into consideration ship's particulars, Pilot Cards (manoeuvre characteristic) and other information (meteorological, navigational warnings and etc.) freely available during normal sea passage, simple formula for depth of the ship's domain according to Rutkowski (2002) can be presented as follows:

– Using precisely Barrass method for estimating ship's squat: (with limitation: $0{,}5 \leq C_B \leq 0{,}9$; $0 \leq t/L \leq 0{,}005$; $1{,}1 \leq h/T \leq 1{,}4$):

$$G_D = n \cdot T_{\max} + 0{,}66 \cdot m \cdot h_f + k \cdot \left(\frac{1}{30} \cdot C_B \cdot \left(\frac{BT}{bh - BT} \right)^{\frac{2}{3}} \cdot v_d^{2,08} \right) \text{[m]} \qquad (24)$$

– Using simplified Barrass method for estimating ship's squat in shallow water (with limitation: $1{,}1 \leq h/T \leq 1{,}2$):

$$G_D = n \cdot T_{\max} + 0{,}66 \cdot m \cdot h_f + k \cdot \left(0{,}01 \cdot C_B . v^2\right) \text{[m]} \qquad (25)$$

where: G_D – depth of ship's domain calculated vertically down from water line (line showing actual ship's draft) [m]; B,L,T_{max}, C_B – ship's particulars: beam B[m], length L[m], maximum draught T[m], block coefficient C_B [-]; v – speed over ground, [kn]; b, H, h_f – area characteristics: depth H[m], wide b [m], wave's height (swell) [m]; n – numeral coefficient (factor) ($1{,}1 \leq n \leq{,}1{,}3$) dependent on type of sea areas and sea bottoms, which determines ship's static vertical navigational reserve. In this paper $n = 1{,}2$ (see table 17); m – numeral coefficient (factor) ($0{,}5 \leq m \leq 1{,}5$) dependent on ship's particulars: v, B, L, C_B and waves characteristics: λ,h_f and q. See table 13; k - numeral coefficient (factor) ($1{,}0 \leq k \leq 2{,}0$) dependent on ship's particulars, type of sea areas and navigational situation (overtaking, crossing, sailing in ice, navigating in restricted sea areas or shallow waters and etc.). The fact that in normal sea passage we cannot exactly estimate all ship's or area's parameters, such as for example ship's squat, depth etc. results in this factor. In this paper $k = 1{,}0$.

Additionally when we accept that navigational risk R_{NG} will equal zero when $G_D = H_N$ then after transformation of the formula (24) or (25) comparatively to unknown T, we can estimate maximum ship's draught in restricted sea area. As an example using simplified formula (25) with limitation: $1{,}1 \leq h/T \leq 1{,}2$, the maximum ship's draught in shallow water can be presented as below:

$$T_{\max} = \frac{H_N - 0{,}66 \cdot m \cdot h_f - k \cdot \left(0{,}01 \cdot C_B . v^2\right)}{n} \text{ [m]} \qquad (26)$$

where: T_{max} – maximum draught of the vessel T [m]; H_N - navigational depth of the sea H [m]; C_B – block coefficient C_B [-]; v – speed over ground, [kn]; h_f – wave's height (swell) [m]; n – numeral coefficient (factor) ($1{,}1 \leq n \leq 1{,}3$) dependent on type of sea areas and sea bottoms, which determines ship's

Table 12. Numeral coefficient (factor) dependent on type of sea areas and sea bottoms, which determines ship's static vertical navigational reserve.

n	Type of the sea area	Type of the sea bottom
1,1	Port area, internal and inshore channels	Mud
1,15	Road, Approaching channels to the port, inshore area	Sand
>1,2	Open sea	Rock, Stone

Table 13. Numeral coefficient (factor) dependent on ship's particulars: v,B,L,C_B and waves characteristics: λ,h_f and q.

m	Sea wave direction equal with ship's heading line (waves from ahead or astern of the vessel q ≈ 000° or 180°)	Sea wave direction perpendicular to ship's heading (waves from the port or starboard beam of the vessel, q ≈ 090°)
0,500	When: $v = 0$ and $L > \lambda$	When: $v = 0$ and $B > 0{,}5\cdot\lambda$
1,000	When: $v \geq 10$ kn and $L > \lambda$	When: $v \geq 10$ w and $B > 0{,}5\cdot\lambda$
1,125	When: $v < 10$ kn and $L < 0{,}5\cdot\lambda$	When: $v < 10$ w and $B < 0{,}5\cdot\lambda$
≥1,25 0	When: $v \geq 10$ kn and $L < 0{,}5\cdot\lambda$	When: $v \geq 10$ w and $B < 0{,}5\cdot\lambda$

Table 14. Maximum ship's draught in shallow water estimated by means of formulae (26) for average ($h_f = 3$ m, $\lambda = 150$ m, $\Delta h = \pm 0{,}30$ m, $H_{N1} = 17{,}70$ m) and extreme ($h_f = 5$ m, $\lambda = 160$ m, $\Delta h = \pm 0{,}60$ m, $H_{N2} = 17{,}40$ m) weather condition, with limitation: $1{,}1 \leq h/T \leq 1{,}2$, for different ship's type (her block coefficient C_B) and different ship's speed v. (n = 1,20; m = 1 and k = 1,0).

Speed	4 kn		6 kn		8 kn	
C_B	*Average*	*Extreme*	*Average*	*Extreme*	*Average*	*Extreme*
0,5	13,03	11,68	12,95	11,60	12,83	11,48
0,6	13,02	11,67	12,92	11,57	12,78	11,43
0,7	13,01	11,66	12,89	11,54	12,73	11,38
0,8	12,99	11,64	12,86	11,51	12,67	11,32
0,9	12,98	11,63	12,83	11,48	12,62	11,27
1,0	12,97	11,62	12,80	11,45	12,57	11,22
Speed	10 kn		12 kn		14 kn	
C_B	*Average*	*Extreme*	*Average*	*Extreme*	*Average*	*Extreme*
0,5	12,68	11,33	12,50	11,15	12,28	10,93
0,6	12,60	11,25	12,38	11,03	12,12	10,77
0,7	12,52	11,17	12,26	10,91	11,96	10,61
0,8	12,43	11,08	12,14	10,79	11,79	10,44
0,9	12,35	11,00	12,02	10,67	11,63	10,28
1,0	12,27	10,92	11,90	10,55	11,47	10,12

static vertical navigational reserve. In this paper $n = 1{,}2$ (see table 12); m – numeral coefficient (factor) ($0{,}5 \leq m \leq 1{,}5$) dependent on ship's particulars: *v*, B, L, C_B and waves characteristics: λ, h_f and q. See table 13; *k* – numeral coefficient (factor) ($1{,}0 \leq k \leq 2{,}0$) dependent on ship's particulars, type of sea areas and navigational situation (overtaking, crossing, sailing in ice, navigating in restricted sea areas or shallow waters and etc.). The fact that in normal sea passage we cannot exactly estimate all ship's or area's parameters, such as for example ship's squat, depth etc. results in this factor. In this paper $k = 1{,}0$.

CONCLUSIONS

To depict maximum draught of a vessel we can use practical method which incorporates risk of navigational and three-dimensional model of ship's domain.

Maximum ship's draught in shallow water estimated by means of formulae (26), with limitation: $1{,}1 \leq h/T \leq 1{,}2$, are presented in table 14. Maximum ship's draught is estimated in shallow water (S of Stolpe Bank) with navigational depth no less than $H_N = G_D = 18{,}0$ m estimated with reference to chart datum related to MSL (Mean Sea Level).

Additionally, maximum ship's draught is estimated for average (wave's height (swell) no more than $h_f = 3$ m and length no more than $\lambda = 150$ m, maximum fluctuation of the sea water level observed in the area $\Delta h = \pm 0{,}30$ m, $H_{N1} = 17{,}70$ m) and extreme weather condition (winter time, maximum wave's height (swell) about $h_f = 5$ m and length about $\lambda = 160$ m, maximum fluctuation of the sea water level observed in the area $\Delta h = \pm 0{,}60$ m, $H_{N2} = 17{,}40$ m) for different ship's type (her block coefficient C_B) and different ship's speed. Numeral coefficients (factors): n = 1,20 (see table 12), m = 1 (see table 13) and k = 1,0.

The probability that we can expect extreme weather condition ($H_{5\%} > 3{,}00$ m) in the researched area (S of Stolpe Bank) is less than 0,3% (See table 6). Extreme weather condition can be expected only during the winter from November to February with strong and long-lasting winds from W and NE.

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11.8
Asymptotic theory of ship motions in regular waves under shallow water conditions

Y.L. Vorobyov
Marine Engineering Bureau, Ukraine

M.S. Stasenko
Odessa National Maritime University, Odessa, Ukraine

ABSTRACT: The hydrodynamic theory of ship motions in shallow water under the action of regular waves is discussed. The boundary value problem for velocity potential is solved using the Matched Asymptotic Expansion Method (MAEM). The solution is based on Fourier – Michell integral transformation technique and characteristics of Helmholtz and Klein – Gordon equations. Using the obtained results formulae for hydrodynamic characteristics are derived. The application of these formulae demonstrated good coincidence of the results of calculations and model experiments carried out in towing tank of Odessa National Maritime University.

1 INTRODUCTION

The intensification of shipping gave rise to complication of navigating conditions at sea roots and in recent years over 75% of navigation accidents occurred in restricted waters and bounded waterways. The growth of merchant ship dimensions during the last decades led to the situation in which vast regions of oceans and seas become comparatively shallow.

The wrecks of modern large vessels getting stranded or collided are accompanied by serious economical losses and negative ecological consequences.

The estimation of ship motion characteristics in restricted waterways is necessary not only for eliminating the possibilities or minimizing the number of accidents, but for substantiation of sea routes dimensions in the proximity of ports as well.

Modern theoretical and experimental hydrodynamics provides us with a great amount of information for predicting seakeeping qualities of ships in open deep sea. On the contrary such an information for a vessel sailing in shallow water is comparatively poor and the proper methods are not widely developed. Such a situation may be explained by virtue of the additional difficulties arising in the theoretical investigation of the potential boundary value problems for a ship propagating in shallow water conditions. First of all the complicacy of the singularities method is ten times higher for shallow water potential problems in comparison with the unbounded sea ones. Then the strip method widely used in practical calculations is inconsistent with the physical reality and often causes insoluble problems when using in shallow water cases with clearly expressed three dimensional water flow phenomena.

Thus a new approach for investigating ship hydrodynamic problems free from difficulties of classical method of singularities and shortcomings of strip method is vital. Such approach is demonstrated in this paper.

2 BOUNDARY VALUE PROBLEM FOR VELOCITY POTENTIAL

If the water around a ship is considered as inviscid incompressible fluid the important hydrodynamic information is derived from the solutions of boundary value problems for the velocity potential. Founded on basic physical principles the nonlinear problems with apriori unknown boundaries are simplified by linearization and the solutions of corresponding linear problems are practically used. Consider a vessel floating with a zero forward speed in shallow water with the depth H under the action of regular waves $\zeta_{\theta} = r_{\theta} e^{i\sigma t}$, r_{θ} and σ being wave amplitude and circular frequency accordingly.

The longitudinal x and transverse y axes of the Cartesian coordinate system are taken on the free surface of water and the vertical axe z is pointed downward.

The potential function $\Phi(x, y, z, t)$ can be divided into cosine $\Phi^{\tilde{n}}$ and sine Φ^{s} parts

$$\Phi(x, y, z, t) = \mathrm{Re}\left[\Phi^{c}(x, y, z) - i\Phi^{s}(x, y, z)\right]e^{i\sigma t} \qquad (1)$$

It is systematically demonstrated in investigations of Y.L. Vorobyov (Vorobyov, 2002), that estimation of added inertia, damping, coupling coefficients and exciting forces can be done using asymptotic values of radiation potential. So we can avoid the necessity of treating the wave scattering problem and difficulties of integration in the hull proximity.

Consider the ship performing longitudinal harmonic oscillations with circular frequency σ. The potential functions $\Phi_j^{\tilde{n},s}(x,y,z), j=1,3,5$ must satisfy the following differential systems

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)\Phi_j^{c,s}(x,y,z)=0,(x,y,z)\in E_0; \quad (2)$$

$$\left(\frac{\partial}{\partial z}+\frac{\sigma^2}{g}\right)\Phi_j^{c,s}(x,y,0)=0,(x,y)\in\Sigma_0; \quad (3)$$

$$\frac{\partial}{\partial n}\Phi_j^{c,s}(x,\pm y,z)=u_j(x,z),\ (x,y,z)\in S; \quad (4)$$

$$\frac{\partial}{\partial z}\Phi_j^{c,s}(x,y,H)=0,\quad(-\infty<x,y<\infty). \quad (5)$$

If the ship is performing transverse harmonic oscillation with circular frequency σ, the potential functions $\Phi_j^{c,s}(x,y,z), j=2,6$ must satisfy the differential systems (2), (3), (5) and hull conditions

$$\frac{\partial}{\partial n}\Phi_j^{c}(x,\pm y,z)=\pm v_j(x,z), \frac{\partial}{\partial n}\Phi_j^{s}(x,\pm y,z)=0, \quad (x,y,z)\in S. \quad (6)$$

Both systems must satisfy radiation conditions in the infinity.

If the velocity of oscillations is taken to be unity, $u_j(x,z)$ and $v_j(x,z)$ are for longitudinal oscillations $j=1,3,5$

$$u_1(x,z)=\cos(N,x), u_3(x,z)=\cos(N,z), \quad u_5(x,z)=z\cos(N,x)-x\cos(N,z), \quad (7)$$

and for transverse oscillations $j=2,6$

$$v_2(x,z)=\cos(N,y), v_6(x,z)= =y\cos(N,x)-x\cos(N,y) \quad (8)$$

Now let us consider ship as slender body, supposing that $B/L=O(\varepsilon)$, $T/L=O(\varepsilon)$, L, B, T being her length, beam and draft, $\varepsilon\ll 1$ and the hull varies slowly along the longitudinal axe. Under this assumption matched asymptotic expansion method (MAEM) is used for solving the potential problems.

According to MAEM the flow field is divided into two zones: far field zone where $y/L=O(1)$ and near field zone in which $y/L=O(\varepsilon)$. The condition along the boundary between the zones are not formulated and satisfied in the process of matching the solutions in far and near fields along the their boundary.

3 FAR FIELD SOLUTIONS

If the observation point is located in the far field as $\varepsilon\to 0$ the hull degenerates into a cut $\delta=-L/2\le x\le L/2$ of free surface plane $z=0$. The potential functions $\Phi_j^{c,s}$ are harmonic (2) in the layer $0\le z\le H$ with ship centerplane $y=0$ excluded, satisfy free surface (**??**) and radiation conditions. The boundary conditions on the centerplane $y=\pm 0$, that is on the inner boundary of the outer zone are not formulated as soon as the hull (with its centerplane) belongs to inner zone. The only identities come from the physical considerations

$$\Phi_j^{c,s}(x,-y,z)=\Phi_j^{c,s}(x,+y,z); \frac{\partial}{\partial y}\Phi_j^{c,s}(x,-y,z)= =-\frac{\partial}{\partial y}\Phi_j^{c,s}(x,+y,z), y>0, j=1,3,5; \quad (9)$$

$$\Phi_j^{c,s}(x,-y,z)=-\Phi_j^{c,s}(x,+y,z); \frac{\partial}{\partial y}\Phi_j^{c,s}(x,-y,z)= =\frac{\partial}{\partial y}\Phi_j^{c,s}(x,+y,z), y>0, j=2,6. \quad (10)$$

In accordance with (9), (10) the boundary conditions on the centerplane $y=\pm 0$ are taken in the form

$$\frac{\partial}{\partial y}\Phi_j^{c}(x,\pm 0,z)=\pm f_j(x,z); \frac{\partial}{\partial y}\Phi_j^{s}(x,\pm 0,z)=0, j=1,3,5; \quad (11)$$

$$\Phi_j^{c}(x,\pm 0,z)=\pm g_j(x,z); \Phi_j^{s}(x,\pm 0,z)=0, j=2,6, \quad (12)$$

where unknown functions $f_j(x,z)$ and $g_j(x,z)$ are taken as known ones for a moment.

Let us find the solution of the outer problem (2), (3), (11), (12), (5) for cosine amplitude $\Phi_j^c(x,y,z)$ of velocity potential $\Phi_j(x,y,z,t)$. Using the Fourier method for the outer differential problem we find the expansions for $\Phi_j^c(x,y,z)$

$$\Phi_j^c(x,y,z)=F_j^0(x,y)Z_0(z)+\sum_{m=1}^{\infty}F_j^m(x,y)Z_m(z); \quad (13)$$

$$F_j^0(x,y)=\frac{1}{H}\int_0^H\Phi_j^c(x,y,z)Z_0(z)dz; \quad F_j^m(x,y)=\frac{1}{H}\int_0^H\Phi_j^c(x,y,z)Z_m(z)dz. \quad (14)$$

The eigen functions $Z_0(z)$, $Z_m(z)$ form a complete orthogonal set in $[0,H]$ with mean square value of 1:

$$Z_0(z)=(\mathrm{N}_0)^{-\frac{1}{2}}ch\alpha_0(z-H), Z_m(z)=(\mathrm{N}_m)^{-\frac{1}{2}}\times \times ch\alpha_m(z-H); \mathrm{N}_0(z)=\frac{1}{2}\left(1+\frac{sh2\alpha_0H}{2\alpha_0H}\right); \quad \mathrm{N}_m(z)=\frac{1}{2}\left(1+\frac{\sin 2\alpha_mH}{2\alpha_mH}\right), \quad (15)$$

where $\alpha_0=$,real positive root of the equation

$$\frac{\sigma^2}{g}=\alpha_0 th\alpha_0 H \quad (16)$$

and $\alpha_1 < \alpha_2 < \alpha_3 < =$ subsequence of real positive roots of the equation

$$\alpha_m tg\alpha_m H + \frac{\sigma^2}{g} = 0\,. \tag{17}$$

As soon as $\Phi_j^c(x,y,z)$ is harmonic and the eign function system is orthogonal, $F_j^0(x,y)$ and $F_j^m(x,y)$ satisfy the Helmholtz and Klein-Gordon equations

$$\begin{aligned}&\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\alpha_0{}^2\right)F_j^0(x,y)=0,\\&\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}-\alpha_m{}^2\right)F_j^m(x,y)=0.\end{aligned} \tag{18}$$

Taking in mind, that for $j=1,3,5\ \frac{\partial}{\partial y}\Phi_j^c(x,\pm 0,z)=\pm f_j(x,z)$, the boundary conditions for equations (18) according to (14) are to be taken in the form

$$\begin{aligned}&\frac{\partial}{\partial y}F_j^0(x,\pm 0)=\pm\frac{1}{2}\gamma_j^0(x),\\&\frac{\partial}{\partial y}F_j^m(x,\pm 0)=\pm\frac{1}{2}\gamma_j^m(x),\ -L/2\le x\le L/2,\end{aligned} \tag{19}$$

where

$$\begin{aligned}&\gamma_j^0(x)=\frac{2}{H}\int_0^H f_j(x,z)Z_0(z)\mathrm{d}z;\\&\gamma_j^m(x)=\frac{2}{H}\int_0^H f_j(x,z)Z_m(z)\mathrm{d}z.\end{aligned} \tag{20}$$

According to Green theorem and conditions (19), (20), after using radiation conditions we find for $j=1,3,5$

$$\begin{aligned}\Phi_j^c(x,y,z)=&\frac{1}{2H}Z_0(z)\int_{-L/2}^{L/2}\mathrm{N}_0(\alpha_0R)\int_0^H f_j(\xi,\zeta)Z_0(\zeta)d\xi d\zeta-\\&-\frac{1}{\pi H}\sum_{m=1}^{\infty}Z_m(z)\int_{-L/2}^{L/2}\mathrm{K}_0(\alpha_mR)\int_0^H f_j(\xi,\zeta)Z_m(\xi)d\xi\,d\zeta,\end{aligned} \tag{21}$$

$$\Phi_j^s(x,y,z)=-\frac{1}{2H}Z_0(z)\int_{-L/2}^{L/2}J_0(\alpha_0R)\int_0^H f_j(\xi,\zeta)Z_0(\zeta)d\xi\,d\zeta, \tag{22}$$

where $J_0(\alpha_0R)$, $\mathrm{N}_0(\alpha_0R)$, $\mathrm{K}_0(\alpha_mR)=$ Bessel functions, $R=\sqrt{(x-\xi)^2+y^2}$.

The last formula is based on Green theorem, equations (18), boundary condition $\frac{\partial}{\partial y}\Phi_j^s(x,\pm 0,z)\equiv 0$ and radiation conditions.

Now returning to (18) we find that for $j=2,6$ $\frac{\partial}{\partial y}\Phi_j^c(x,\pm 0,z)=\pm g_j(x,z)$, the boundary condition for equation (18) must be taken in the form

$$F_j^0(x,\pm 0)=\pm\frac{1}{2}\gamma_j^0(x),F_j^m(x,\pm 0)=\pm\frac{1}{2}\gamma_j^m(x). \tag{23}$$

where

$$\begin{aligned}&\gamma_j^0(x)=\frac{2}{H}\int_0^H g_j(x,z)Z_0(z)\mathrm{d}z;\\&\gamma_j^m(x)=\frac{2}{H}\int_0^H g_j(x,z)Z_m(z)\mathrm{d}z,\ j=2,6.\end{aligned} \tag{24}$$

Now taking solutions of (18) that satisfy boundary conditions (23), (24) along the cut $|x|\le L/2$ after using radiation conditions we have

$$\begin{aligned}\Phi_j^c(x,y,z)=&\frac{1}{2H}Z_0(z)\frac{\partial}{\partial y}\int_{-L/2}^{L/2}\mathrm{N}_0(\alpha_0R)\int_0^H g_j(\xi,\zeta)Z_0(\zeta)d\xi\,d\zeta-\\&-\frac{1}{\pi H}\sum_{m=1}^{\infty}Z_m(z)\frac{\partial}{\partial y}\int_{-L/2}^{L/2}\mathrm{K}_0(\alpha_mR)\int_0^H g_j(\xi,\zeta)Z_m(\xi)d\xi\,d\zeta,\end{aligned} \tag{25}$$

$$\begin{aligned}\Phi_j^s(x,y,z)=&-\frac{1}{2H}Z_0(z)\times\\&\times\frac{\partial}{\partial y}\int_{-L/2}^{L/2}J_0(\alpha_0R)\int_0^H g_j(\xi,\zeta)Z_0(\zeta)d\xi d\zeta,\ j=2,6.\end{aligned} \tag{26}$$

4 NEAR FIELD SOLUTIONS MATCHING

To study flow phenomena in the near field the transverse coordinates are stretched $\eta=y/\varepsilon$, $\zeta=z/\varepsilon$ and as $\varepsilon\to 0$ omitting terms of $O(\varepsilon^2)$ we obtain the totality of two dimensional boundary value problems in $x=const$ planes for $\Phi_j^c(\eta,\zeta)$

$$\begin{aligned}&\left(\frac{\partial^2}{\partial\eta^2}+\frac{\partial^2}{\partial\zeta^2}\right)\Phi_j^c(\eta,\zeta)=0,\ (\eta,\zeta)\in e(x);\\&\left(\frac{\partial}{\partial\zeta}+\kappa_1\right)\Phi_j^c(\eta,0)=0;\ \kappa_1=\varepsilon\frac{\sigma^2}{g},|\eta|>\frac{1}{2}b(x);\\&\frac{\partial}{\partial N}\Phi_2^c(\eta,\zeta)=\cos(N,\eta);(\eta,\zeta)\in L^+(x);\\&\frac{\partial}{\partial N}\Phi_3^c(\eta,\zeta)=\cos(N,\zeta);(\eta,\zeta)\in L^+(x);\\&\frac{\partial}{\partial\zeta}\Phi_j^c(\eta,h)=0;|\eta|<\infty,\ j=1,2,3,5,6.\end{aligned} \tag{27}$$

Here $e(x)=$ a fluid domain in a form of strip $\{-\infty<\eta<\infty,\ 0\le\zeta\le h\}$ with frame contour $L^+(x)$ excluded, $b(x)=$ the width of this contour.

The problem for $\Phi_j^s(\eta,\zeta)$ is uniform and has a trivial zero solution. The boundary value problem (27) has to be discussed keeping in mind that for matching procedure the asymptotics of solutions when η tends to infinity are needed. These asymptotics are found using specially worked out procedure. In addition to harmonic potential $\Phi_j^c(\eta,\zeta)$ let us introduce the conjugate harmonic stream function $\Psi_j^c(\eta,\zeta)$ and multi-valued analytical function $U_j(\chi=\eta+iy,)=\Phi_j^c(\eta,\zeta)+i\Psi_j^c(\eta,\zeta)$ being determined outside the close contour $L^{+}(x)UL^{-}(x)$. Various branches of $U_j(\chi)$ differ one from another by function

$$\Delta[U_j] = \frac{ch\lambda_0 hch\lambda_0(\zeta - h)}{2(\lambda_0 h + sh\lambda_0 hch\lambda_0)} \begin{cases} A, & j = 2,6; \\ B, & j = 1,3,5, \end{cases} \tag{28}$$

where $A = P_j(x, \lambda_0)\cos\lambda_0\eta$, $B = -Q_j(x, \lambda_0)\sin\lambda_0\eta$, $\lambda_0 =$ real positive root of the equation

$$\varepsilon\frac{\sigma^2}{g} = \lambda_0 th\lambda_0 h\,. \tag{29}$$

We notice that outer boundaries of inner zone $\eta \to \pm\infty$ are at the same time the inner boundaries of the outer zone $y = \pm 0$. We have from (28) and (29)

$$f_j(x, \pm 0, z) = \pm\frac{1}{2}Q_j(x, \alpha_0)\frac{\alpha_0 ch\alpha_0 Hch\alpha_0(z - H)}{\alpha_0 H + sh\alpha_0 Hch\alpha_0 H}, j = 1,3,5, \tag{30}$$

$$g_j(x, \pm 0, z) = \mp\frac{1}{2}P_j(x, \alpha_0)\frac{ch\alpha_0 Hch\alpha_0(z - H)}{\alpha_0 H + sh\alpha_0 Hch\alpha_0 H}, j = 2,6. \tag{31}$$

Functional coefficients $Q_j(x, \alpha_0)$ and $P_j(x, \alpha_0)$ are determined in the form

$$Q_3(x, \alpha_0) = 4\int_0^{\frac{1}{2}b(x)} \exp\left[-\frac{\sigma^2}{g}Z_0(t)\right] \times \left\{[\alpha_0 A_+(t) + B_+(t)s(t)]\cos\alpha_0 t - \alpha_0 A_+(t)\frac{dZ_0(t)}{dt}\sin\alpha_0 t\right\}dt, \tag{32}$$

$$P_3(x, \alpha_0) = 4\int_0^{\frac{1}{2}b(x)} \exp\left[-\frac{\sigma^2}{g}Z_0(t)\right] \times \left\{[\alpha_0 A_+(t) + B_+(t)s(t)]\sin\alpha_0 t - \alpha_0 A_+(t)\frac{dZ_0(t)}{dt}\cos\alpha_0 t\right\}dt, \tag{33}$$

where $A_+(t) =$ values of potential function under determination on the contour with the equation $z = Z_0(t)$ and $S(t) = \sqrt{1 + \left[\frac{dZ_0(t)}{dt}\right]^2}$.

As soon as $A_+(t)$ is unknown, it is proposed to take its approximate value when the frequency of oscillations tends to infinity. Values of $B_+(t)$ are values of normal derivative of potential function according to the hull boundary conditions. The value of $A_+(t)$ can be easily found using the standard integral equation procedure.

For $f_5(x, \alpha_0)$ and $f_6(x, \alpha_0)$ we find

$$f_5(x, \alpha_0) = -xf_3(x, \alpha_0);\ f_6(x, \alpha_0) = -xf_2(x, \alpha_0) \tag{34}$$

Inserting (30)–(34) into (21), (22) and (25), (26) we actually performed matching of solutions in far and near field zones upon their boundary and get an approximate solutions for five radiation potentials uniformally valid in the whole water domain.

5 HYDRODYNAMIC COEFFICIENTS OF SHIP MOTIONS

It is convenient to find damping and exciting forces according to Haskind-Newman approaches where asymptotic expansions of radiation potentials are used. Thus we avoid the necessity of solving the diffraction problem and simplify calculations because of the simplicity that asymptotics of potential functions have far from ship hull. According to (Haskind, 1973, Newman, 1961) wave exciting forces and moments acting on a vessel may be calculated using such expressions

$$X_j(\beta) = 2\gamma r_0 e^{i\sigma t}[F_c(\beta) - iF_s(\beta)],\ j = 1,3,5\,. \tag{35}$$

$$\left.\begin{matrix} F_c(\beta) \\ F_s(\beta) \end{matrix}\right\} = \int_{-L/2}^{L/2}\int_0^H f_j(\xi, \zeta)(ch\alpha_0\zeta - th\alpha_0 Hsh\alpha_0\zeta)\begin{Bmatrix} \cos(\alpha_0\xi\cos\beta) \\ \sin(\alpha_0\xi\cos\beta) \end{Bmatrix}d\zeta\, d\xi \tag{36}$$

$$X_j(\beta) = \frac{1}{2}\gamma r_0 \sin\beta e^{i\sigma t}[F_s(\beta) + iF_c(\beta)],\ j = 2,6\,. \tag{37}$$

Functions $F_{c,s}(\beta)$ are determined by (36), but for $j = 2, 6$ instead of $f_j(x, z)g_j(x, z)$ is taken. Functions $f_j(x, z)j = 1, 3, 5$ and $g_j(x, zt)j = 2, 6$ are given by (30)–(34).

In expressions (35)–(37) r_0 – incoming wave amplitude, β – angle between longitudinal axe of ship hull and vector of wave crests propagation.

The real parts of (35) and (37) must to be taken into account.

Damping forces and moments are calculated analyzing the energy flow carried of to infinity from ship hull by outgoing waves. According to (Haskind, 1973, Newman, 1959) damping coefficients μ_{ij} are given by formulae

$$\mu_{ij} = q\frac{\rho\sigma\alpha_0\Psi(\alpha_0)}{16} \times \int_{-L/2}^{L/2}\int_{-L/2}^{L/2}(-x)^{\frac{i-3}{2}}Q_i(x, \alpha_0)(-\xi)^{\frac{j-3}{2}} \times Q_j(\xi, \alpha_0)J_0(\alpha_0|x - \xi|)d\xi dx,\ i = 3,5,\ j = 3,5. \tag{38}$$

$\left(\frac{i-3}{2}\right)$, $\left(\frac{j-3}{2}\right)$ are taken equal to zero for $i = j = 1$.

$$\mu_{ij} = -q\frac{\rho\sigma\alpha_0\Psi(\alpha_0)}{32} \times \int_{-L/2}^{L/2}\int_{-L/2}^{L/2}(-x)^{\frac{i-2}{4}}P_i(x, \alpha_0)(-\xi)^{\frac{j-2}{4}} \times P_j(\xi, \alpha_0)[J_0(\alpha_0|x - \xi|) + J_2(\alpha_0|x - \xi|)]d\xi dx,\ i = 2,6,\ j = 2,6, \tag{39}$$

where $q = 2$ if $i = j$, otherwise $q = 1$, $\Psi(\alpha_0) = \frac{1}{\frac{\alpha_0 H}{ch^2\alpha_0 H} + th\alpha_0 H}$, functions $P_i(x, \alpha_0)$ and $Q_i(x, \alpha_0)$ are given by (32)–(34), J_0 and J_2 are Bessel functions.

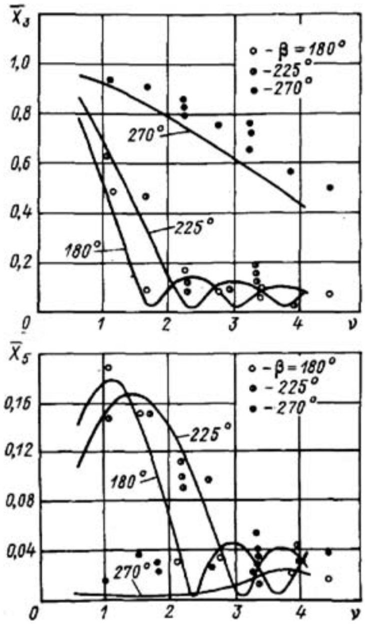


Figure 1. Longitudinal exciting forces.

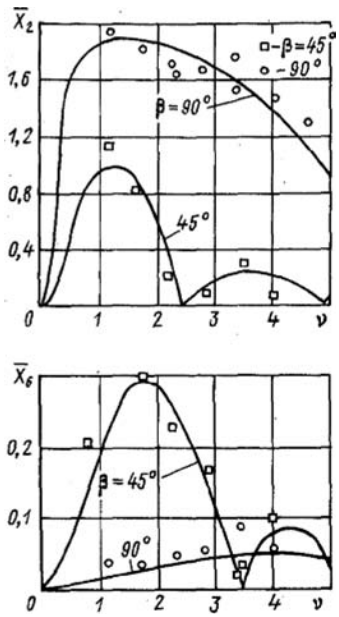


Figure 2. Transverse exciting forces.

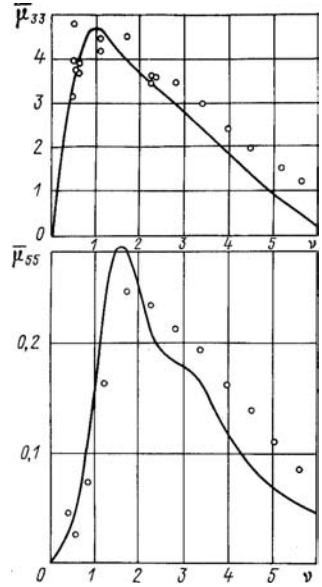


Figure 3. Longitudinal damping.

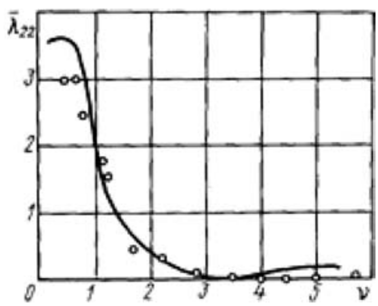
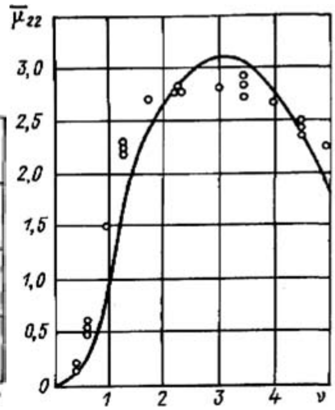


Figure 4. Sway added mass.



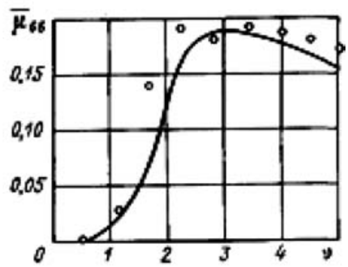


Figure 5. Transverse damping.

For calculation of inertia forces acting on an oscillating vessel potential functions in the near field must be used. To avoid the difficulties of integration the source-like functions in the vicinity of ship hull an alternative method is used. The method is based on the fact proved in (Landau, Lifshits, 1964), discussed and used in (Kotic, Mangulis, 1962).

It was demonstrated that added masses and damping coefficients are proportional to integral sine and cosine transformations of identical functions. It is enough to find a couple of transformations

$$\lambda_{ij}(\sigma)=\lambda_{ij}(\infty)+\frac{2}{\pi}\int_0^{\infty}\frac{\mu_{ij}(x)-\mu_{ij}(\infty)}{x^2-\sigma^2}dx, \qquad (40)$$

$$\mu_{ij}(\sigma)=\mu_{ij}(\infty)-\frac{2\sigma}{\pi}\int_0^{\infty}\frac{\left[\lambda_{ij}(x)-\lambda_{ij}(\infty)\right]}{x^2-\sigma^2}x\,dx, \qquad (41)$$

where $\lambda_{ij}(\sigma)$, $\lambda_{ij}(\infty)$, $\mu_{ij}(\sigma)$, $\mu_{ij}(\infty)=$ added mass and damping coefficients for frequency σ and infinite frequency consequently.

Integrals in (40), (41) are introduced us principle value integrals. It is known that mostly $\mu_{ij}(\infty)\equiv 0$. The value of $\lambda_{ij}(\infty)$ for a ship can easily be calculated using strip method and solving standard integral equation in the layer $0\le z\le H$.

The hydrodynamic characteristics of 200000 DWT tanker (Oortmerssen, 1976) for motions in shallow water conditions $\frac{H}{T}=1.2$ are demonstrated in Fig. 1–5. The values calculated using the results of paper are given by solid lines, while the results of experiments conducted in towing tank Odessa National Maritime University are presented by dots. The coincidence of theoretical and experimental results is satisfactory for practical uses.

Coefficients of added mass, exciting forces and damping are plotted against undimensional frequency $\nu = \sigma\sqrt{\frac{L}{g}}$.

6 CONCLUSION

The results derived on the base of MAEM were used for systematic calculations of hydrodynamic characteristics for a ship floating in regular waves under shallow water conditions.

The calculated values demonstrated good agreement with the results of model experiments conducted in towing tank of Odessa National Maritime University.

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Chapter 12. Methods and algorithms

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

12.1 Stabilization of fractional positive continuous-time linear systems in sectors of left-hand half complex plane by state-feedbacks

T. Kaczorek
Faculty of Electrical Engineering, Białystok Technical University, Poland

ABSTRACT: The stabilization problem of fractional positive linear continuous-time linear systems by state-feedbacks is addressed. The gain matrix of the state feedback is chosen so that the zeros of the closed-loop polynomial are located in a sector of the left-hand half of complex plane. Necessary and sufficient conditions for the solvability of the problem are established and a procedure for computation of a gain matrix of the feedback is proposed. The considerations are illustrated by numerical examples.

1 INTRODUCTION

In positive systems inputs, state variables and outputs take only non-negative values. Examples of positive systems are industrial processes involving chemical reactors, heat exchangers and distillation columns, storage systems, compartmental systems, water and atmospheric pollution models. A variety of models having positive linear systems behaviour can be found in engineering, management science, economics, social sciences, biology and medicine, etc. Positive linear systems are defined on cones and not on linear spaces. Therefore, the theory of positive systems is more complicated and less advanced. An overview of state of the art in positive systems is given in the monographs [3, 5].

The first definition of the fractional derivative was introduced by Liouville and Riemann at the end of the 19th century [13, 20, 22]. This idea has been used by engineers for modelling different process in the late 1960s [13–27]. Mathematical fundamentals of fractional calculus are given in the monographs [13, 14, 19, 20]. The fractional order controllers have been developed in [20, 24]. A generalization of the Kalman filter for fractional order systems has been proposed in [26]. Some others applications of fractional order systems can be found in [15–18, 23–27]. Fractional polynomials and nD systems have been investigated in [4] and the stability of the fractional continuous-time system with delay in [1]. The concept of positive fractional discrete-time linear systems has been introduced in [7] and the reachability and controllability to zero of positive fractional system has been investigated in [8]. The concept of fractional positive continuous - time linear systems has been introduced in [9]. and the reachability and controllability to zero of positive fractional system has been investigated in [8]. The stabilization problem of fractional discrete-time linear systems by state-feedback has been considered in [10]. The problem of positivity and stabilization of 2D linear systems by state-feedbacks have been analysed in [11, 12].

In this paper the stabilization problem of fractional positive linear continuous-time linear systems by state-feedbacks will be addressed. The gain matrix of the state feedback will be chosen so that the zeros of the closed-loop polynomial are located in a sector of the left-hand half of complex plane.

The paper is organized as follows. In section 2 the basic definitions and theorems concerning the positive fractional systems are recalled. The main results of the paper are presented in section 3 and 4. In section 3 the stability of the positive fractional continuous-time linear systems is discussed and the equilibrium point of the systems is introduced. The stabilization problem by state-feedbacks is formulated and solved in section 4. Concluding remarks are given in section 5.

The following notation will be used in the paper. The set of $n \times m$ real matrices will be denoted $\Re^{n \times m}$ and $\Re^n := \Re^{n \times 1}$. The set of $m \times n$ real matrices with nonnegative entries will be denoted by $\Re_+^{m \times n}$ and $\Re_+^n := \Re_+^{n \times 1}$. A matrix A (a vector x) with positive entries (positive components) will be denoted by $A > 0$ ($x > 0$). The set of nonnegative integers will be denoted by Z_+ and the $n \times n$ identity matrix by I_n.

2 POSITIVE FRACTIONAL CONTINUOUS-TIME LINEAR SYSTEMS

In this paper the following Caputo definition of the fractional derivative will be used [19, 22, 27]

$$ {}_0^c D_t^\alpha f(t) = \frac{d^\alpha}{dt^\alpha} f(t) = \frac{1}{\Gamma(n-\alpha)} \int_0^t \frac{f^{(n)}(\tau)}{(t-\tau)^{\alpha+1-n}} d\tau, $$
$$ n-1 < \alpha \le n \in N = \{1,2,...\} \tag{1} $$

where $\alpha \in \Re$ is the order of fractional derivative and

$$f^{(n)}(\tau) = \frac{d^n f(\tau)}{d\tau^n}.$$

Consider the fractional continuous-time linear system described by the state equations

$$\frac{d^\alpha x(t)}{dt^\alpha} = Ax(t) + Bu(t), \quad 0 < \alpha \le 1 \tag{2a}$$

$$y(t) = Cx(t) + Du(t) \tag{2b}$$

where $x(t) \in \Re^n$, $u(t) \in \Re^m$, $y(t) \in \Re^p$ are the state, input and output vectors and $A \in \Re^{n\times n}$, $B \in \Re^{N\times m}$, $C \in \Re^{p\times n}$, $D \in \Re^{p\times m}$.

Theorem 1. The solution of equation (2a) is given by

$$x(t) = \Phi_0(t)x_0 + \int_0^t \Phi(t-\tau)Bu(\tau)d\tau, \quad x(0) = x_0 \tag{3}$$

where

$$\Phi_0(t) = E_\alpha(At^\alpha) = \sum_{k=0}^{\infty} \frac{A^k t^{k\alpha}}{\Gamma(k\alpha+1)} \tag{4}$$

$$\Phi(t) = \sum_{k=0}^{\infty} \frac{A^k t^{(k+1)\alpha-1}}{\Gamma[(k+1)\alpha]} \tag{5}$$

and $E_\alpha(At^\alpha)$ is the Mittage-Leffler matrix function, $\Gamma(x) = \int_0^\infty e^{-}t^{x-1}dt$ is the gamma function.

Proof is given in [9].

Remark 1. From (4) and (5) for $\alpha = 1$ we have

$$\Phi_0(t) = \Phi(t) = \sum_{k=0}^{\infty} \frac{(At)^k}{\Gamma(k+1)} = e^{At}.$$

Definition 1. The fractional system (2) is called (internally) positive if and only if $x(t) \in \Re^n_+$ and $y(t) \in \Re^p_+$ for $t \ge 0$ for any initial conditions $x_0 \in \Re^n_+$ and all inputs $u(t) \in \Re^m_+$, $t \ge 0$.

A square real matrix $A = [a_{ij}]$ is called the Metzler matrix if its off-diagonal entries are nonnegative, i.e. $a_{ij} \ge 0$ for $i \ne j$ [3, 5]. The set of $n \times n$ Metzler matrices will be denoted by M_n.

Lemma 1. [9] Let $A \in \Re^{n\times n}$ and $0 < \alpha \le 1$. Then

$$\Phi_0(t) = \sum_{k=0}^{\infty} \frac{A^k t^{k\alpha}}{\Gamma(k\alpha+1)} \in \Re^{n\times n}_+ \quad \text{for } t \ge 0 \tag{6}$$

and

$$\Phi(t) = \sum_{k=0}^{\infty} \frac{A^k t^{(k+1)\alpha-1}}{\Gamma[(k+1)\alpha]} \in \Re^{n\times n}_+ \quad \text{for } t \ge 0 \tag{7}$$

if and only if A is a Metzler matrix, i.e. $A \in M_n$.

Theorem 2. The fractional continuous-time system (2) is internally positive if and only if

$$A \in M_n, \quad B \in \Re^{n\times m}_+, \quad C \in \Re^{p\times n}_+, \quad D \in \Re^{p\times m}_+ \tag{8}$$

Proof is given in [9].

3 STABILITY OF THE POSITIVE FRACTIONAL SYSTEMS

Definition 2. The positive fractional system

$$\frac{d^\alpha x(t)}{dt^\alpha} = Ax(t), \quad A \in M_n, \quad 0 < \alpha \le 1 \tag{9}$$

is called asymptotically stable (shortly stable) if and only if

$$\lim_{t\to\infty} x(t) = \lim_{t\to\infty} \Phi_0(t)x_0 = 0 \tag{10}$$

for all $x_0 \in \Re^n_+$.

The characteristic polynomial of (9) has the form

$$\det[I_n s^\alpha - A] = (s^\alpha)^n + a_{n-1}(s^\alpha)^{n-1} + \ldots + a_1 s^\alpha + a_0. \tag{11}$$

Substitution of

$$\lambda = s^\alpha \tag{12}$$

into (11) yields

$$\det[I_n\lambda - A] = \lambda^n + a_{n-1}\lambda^{n-1} + \ldots + a_1\lambda + a_0. \tag{13}$$

Let us denote $\arg s = \phi$ and $\arg \lambda = \varphi$. Then from (12) we have

$$\varphi = \alpha\phi. \tag{14}$$

From (11), (13) and (14) for $\varphi = \frac{\pi}{2}$ we have the following corollary.

Corollary. If the zeros of the characteristic polynomial (13) are located in the left-hand half of complex plane then the zeros of the characteristic polynomial (11) are located in the sector defined by $\phi = \frac{\pi}{2\alpha}$ in the left-hand half complex plane (Fig).

Theorem 3. The zeros of the characteristic polynomial (11) are located in the sector $\phi = \frac{\pi}{2\alpha}$ if and only if one of the following equivalent conditions is satisfied:

1) All coefficient of the characteristic polynomial (13) are positive, i.e. $a_i \ge 0$ for $i = 0, 1, \ldots, n-1$.
2) All leading principle minor of the matrix

$$-A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \tag{15}$$

are positive, i.e.

$$|a_{11}| > 0, \quad \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} > 0, \ldots, \det[-A] > 0 \tag{16}$$

3) There exists a strictly positive vector $\lambda > 0$ ($\lambda \in \Re^n_+$) such that

$$A\lambda > 0 \quad \text{(strictly negative)} \tag{17}$$

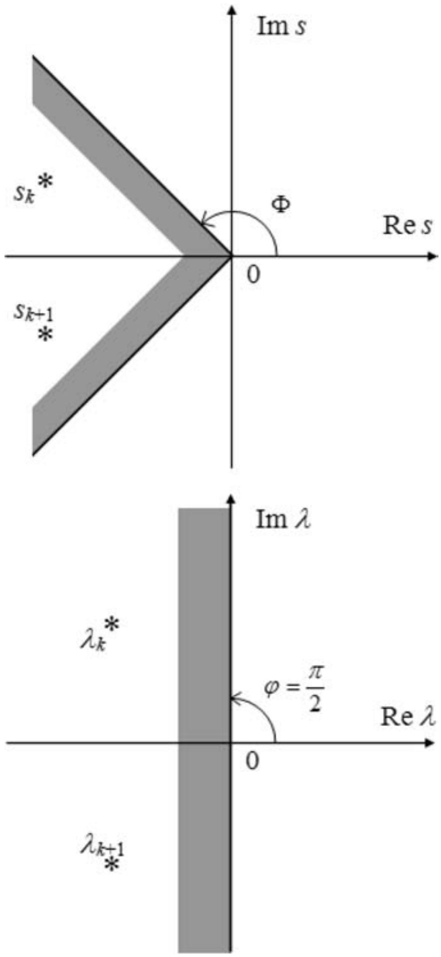

Figure 1.

Proof. For positive fractional system $A \in M_n$ and it is well-known [5 p. 64] that the system is stable if and only if the polynomial (13) has positive coefficients a_i, $i = 0, 1, \ldots, n-1$.

In [6] it was also shown that the condition 1) and 2) are equivalent. It is also well-known [6] that if $A \in M_n$ then the conditions 2) and 3) are also equivalent. •

Definition 3. The vector $x_e \in \Re_+^n$ is called the equilibrium point of the stable positive system (2a) for constant input $u \in \Re_+^m$ ($u(t) = u$) if and only if

$$Ax_e + Bu = 0. \tag{18}$$

If $Bu = 1_n = [1 \ \ldots \ 1]^T \in \Re_+^n$ (T denotes the transpose) then from (17) we have

$$x_e = -A^{-1}\mathbf{1}_n > 0 \tag{19}$$

since for stable system $-A^{-1} \in \Re_+^{n\times n}$ [5].

Remark 2. As strictly positive vector λ in (17) the equilibrium point (19) can be chosen since

$$A\lambda = A(-A^{-1}\mathbf{1}_n) = -\mathbf{1}_n. \tag{20}$$

4 STABILIZATION OF THE FRACTIONAL LINEAR SYSTEMS BY STATE-FEEDBACKS

Consider the fractional linear system (2) with the state-feedback

$$u(t) = Kx(t) \tag{21}$$

where $K \in \Re^{m\times n}$ is a gain matrix.

Substituting (21) in (2a) we obtain the closed-loop system

$$\frac{d^\alpha x(t)}{dt^\alpha} = A_c x(t), \quad 0 < \alpha \le 1 \tag{22}$$

where

$$A_c = A + BK. \tag{23}$$

We are looking for a gain matrix $K \in \Re^{m\times n}$ such that the closed-loop system (22) is positive, i.e. $A_c \in M_n$ and the zeros of the polynomial (11) are located in the sector $\phi = \frac{\pi}{2\alpha}$.

Theorem 4. The closed-loop fractional system (22) is positive and the zeros of the polynomial (**??**) are located in the $\phi = \frac{\pi}{2\alpha}$ sector if and only if there exists a diagonal matrix

$$\Lambda = \mathrm{diag}[\lambda_1, \ldots, \lambda_n] \tag{24}$$

with positive diagonal entries $\lambda_k > 0$ $k = 1, \ldots, n$ and a real matrix $D \in \Re^{m\times n}$ such that the following condition are satisfied

$$A\Lambda + BD \in M_n \tag{25}$$

$$(A\Lambda + BD)\mathbf{1}_n < 0 \tag{26}$$

The gain matrix K is given by the formula

$$K = D\Lambda^{-1}. \tag{27}$$

Proof. First we shall show that the closed-loop system (22) is positive if and only if (25) holds. Using (27) and (23) we obtain

$$A_c = A + BK = A + BD\Lambda^{-1} = (A\Lambda + BD)\Lambda^{-1} \in M_n \tag{28}$$

if and only if the condition (25) is satisfied.

Taking into account that

$$K\Lambda\mathbf{1}_n = D\Lambda^{-1}\Lambda\mathbf{1}_n = D\mathbf{1}_n \text{ and } \Lambda\mathbf{1}_n = \lambda \tag{29}$$

and using (17) we obtain

$$A_c\lambda = (A + BK)\Lambda\mathbf{1}_n = (A\Lambda + BD)\mathbf{1}_n < 0. \tag{30}$$

Therefore, by Theorem 3 the zeros of the characteristic polynomial (11) are located in the sector $\phi = \frac{\pi}{2\alpha}$ if and only if the condition (26) is satisfied.•

If the conditions of Theorem 4 are satisfied then the problem of stabilization can be solved by the use of the following procedure.

Procedure

Step 1. Choose a diagonal matrix (24) with $\lambda_k > 0$ $k = 1, \ldots, n$ and a real matrix $D \in \Re^{m\times n}$ satisfying the condition (25) and (26).

Step 2. Using the formula (27) compute the gain matrix K.

Example 1. Given the fractional system (2a) with $\alpha = 0.8$ and the matrices

$$A = \begin{bmatrix} 1 & 1 & -1 \\ 1 & -3 & 0 \\ 0 & -1 & 2.5 \end{bmatrix}, \quad B = \begin{bmatrix} 0 & 1 \\ 0 & 0 \\ 1 & 0 \end{bmatrix}. \tag{31}$$

Find a gain matrix $K \in \Re^{2\times 3}$ such that the closed-loop system is positive and all zeros of its characteristic polynomial are located in the sector $\phi = \frac{5}{6}\pi$.

It is easy to check that the fractional system with (30) is not positive since the matrix A is not a Metzler matrix.

Using Procedure we obtain the following

Step 1. In this case we choose

$$\Lambda = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \quad D = \begin{bmatrix} 0.5 & 2 & -3.5 \\ -4 & 0 & 1.4 \end{bmatrix} \tag{32}$$

and we check the condition (25)

$$A\Lambda + BD = \begin{bmatrix} 1 & 1 & -1 \\ 1 & -3 & 0 \\ 0 & -1 & 2.5 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix} + \begin{bmatrix} 0 & 1 \\ 0 & 0 \\ 1 & 0 \end{bmatrix}\begin{bmatrix} 0.5 & 2 & -3.5 \\ -4 & 0 & 1.4 \end{bmatrix} =$$

$$= \begin{bmatrix} -3 & 2 & 0.4 \\ 1 & -6 & 0 \\ 0.5 & 0 & -1 \end{bmatrix} \in M_3$$

and the condition (26)

$$(A\Lambda + BD)\mathbf{1}_n = \begin{bmatrix} -3 & 2 & 0.4 \\ 1 & -6 & 0 \\ 0.5 & 0 & -1 \end{bmatrix}\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} -0.6 \\ -5 \\ -0.5 \end{bmatrix}.$$

Therefore, the conditions are satisfied.

Step 2. Using (27) we obtain the gain matrix

$$K = D\Lambda^{-1} = \begin{bmatrix} 0.5 & 2 & -3.5 \\ -4 & 0 & 1.4 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix}^{-1} = \begin{bmatrix} 0.5 & 1 & -3.5 \\ -4 & 0 & 1.4 \end{bmatrix}.$$

The closed-loop system is positive since the matrix

$$A_c = A + BK = \begin{bmatrix} -3 & 1 & 0.4 \\ 1 & -3 & 0 \\ 0.5 & 0 & -1 \end{bmatrix}$$

is a Metzler matrix.

The characteristic polynomial

$$\det[I_n\lambda - A_c] = \begin{vmatrix} \lambda+3 & -1 & -0.4 \\ -1 & \lambda+3 & 0 \\ -0.5 & 0 & \lambda+1 \end{vmatrix} = \lambda^3 + 7\lambda^2 + 13.8\lambda + 7.4$$

has positive coefficient. Therefore, zeros of the characteristic polynomial of the closed system are located in the desired sector $\phi = \frac{5}{6}\pi$.

5 CONCLUDING REMARKS

The stabilization problem of fractional positive linear continuous-time systems by state-feedbacks so that the zeros of the closed-loop polynomial are located in sector of the left-hand half of complex plane has been addressed. Necessary and sufficient conditions for the solvability of the problem have been established. A procedure for computation of a gain matrix of the feedback has been proposed and illustrated by numerical examples. These considerations can be easily extended for fractional positive continuous-time linear systems with delays. Extensions of these approach for fractional positive 2D hybrid linear systems and fractional positive 2D continuous-time linear systems are open problems.

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12.2
The comparison of safe control methods in marine navigation in congested waters

J. Lisowski
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The paper introduces comparison of five methods of safe ship control in collision situation: multi-stage positional non-cooperative and cooperative game, multi-step matrix game, dynamic and kinematics optimisation with neural constrains of state control process. The synthesis of computer navigator decision supporting algorithms with using dual linear programming and dynamic programming methods has been presented. The considerations have been illustrated an examples of a computer simulation the algorithms to determine the safe own ship's trajectory in situation of passing a many of the ships encountered at sea.

1 MATHEMATICAL MODELS OF SAFE SHIP CONTROL PROCESS

1.1 *Base model*

As the process of steering the ship in collision situations, when a greater number of objects is encountered, often occurs under the conditions of indefiniteness and conflict, accompanied by an inaccurate co-operation of the objects within the context of COLREG Regulations then the most adequate model of the process which has been adopted is a model of a dynamic game, in general of *j* tracked ships as objects of steering (Cahill 2002, Lisowski 2004b, 2005d, 2007b, Sandom 2004).

The diversity of selection of possible models directly affects the synthesis of the ship's handling algorithms which are afterwards effected by the ship's handling device directly linked to the ARPA system and determines the effects of the safe and optimal control. The properties of the process are described by the state equation (Isaacs 1965):

$$\dot{x}_i = f_i[(x_0^{\vartheta_0},\ x_j^{\vartheta_j}),(u_0^{\nu_0},\ u_j^{\nu_j}),t]\ j=1,\dots,m \qquad (1)$$

where $\vec{x}_0^{\vartheta_0}(t) - \vartheta_0$ dimensional vector of the process state of the own ship determined in a time span $t \in [t_0, t_k]$; $\vec{x}_j^{\vartheta_j}(t) - \vartheta_j$ dimensional vector of the process state for the *j-th* met ship; $\vec{u}_o^{\nu_0}(t) - \nu_0$ dimensional control vector of the own ship; $\vec{u}_j^{\nu_j}(t) - \nu_j$ dimensional control vector of the *j-th* met ship.

The constraints of the control and the state of the process are connected with the basic condition for the safe passing of the ships at a safe distance D_s in compliance with COLREG Rules, generally in the following form (Engwerda 2005):

$$g_j(x_j^{\vartheta_j},\ u_j^{\nu_j}) \le 0 \qquad (2)$$

Goal function has form of the payments – the integral payment and the final one:

$$I_0^j = \int_{t_0}^{t_k} [x_0^{\vartheta_0}(t)]^2 dt + r_j(t_k) + d(t_k) \ \rightarrow \min \qquad (3)$$

The integral payment represents loss of way by the own ship while passing the encountered ships and the final payment determines the final risk of collision $r_j(t_k)$ relative to the *j-th* ship and the final deflection of the own ship $d(t_k)$ from the reference trajectory (Lisowski 2000a, 2002, 2005a,c, 2008b, Nisan 2007, Nowak 2005, Osborna 2004).

1.2 *Approximate models*

Having regard to a high complexity of the base model in the form of a model of a dynamic game for the practical synthesis of safe steering algorithms various simplified models are formulated, such as for example:

- multi-stage positional game
  - non-cooperative game
  - cooperative game
- multi-step matrix game
- dynamic model with neural constraints
- kinematic model
  - classical model
  - fuzzy model
  - static model
  - speed triangle model.

The degree of simplification is dependent on a control method applied (Lavalle 2006, Lisowski 2005b, 2006b, 2007a,c, 2008d, Straffin 2001).

2 ALGORITHMS OF SAFE SHIP CONTROL

Each particular approximated model of process may be assigned respective methods of safe control of ship (Table 1).

Table 1. Algorithms of determining ship strategies.

Process models	Control methods	Computer supporting algorithms	Type of decision
Multi-stage positional game	Dual linear programming	NPG CPG	Positional game trajectory
Multi-step matrix game	Dual linear programming	MG	Risk game trajectory
Dynamic	Dynamic programming, Artificial neural network	DO	Dynamic optimal trajectory
Kinematic	Linear programming Fuzzy Control	KO	Kinematic optimal trajectory
Static	Linear programming Fuzzy control	OM	Optimal manoeuvre

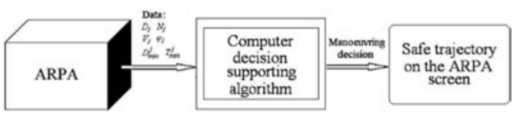

Figure 1. The system structure of computer support of navigator decision in collision situation.

In practice, methods of selecting a manoeuvre assume a form of appropriate steering algorithms supporting navigator decision in a collision situation. Algorithms are programmed into the memory of a Programmable Logic Controller PLC.

This generates an option within the ARPA anti-collision system or a training simulator (Fig. 1).

2.1 *Algorithm of non-cooperative positional game NPG*

The optimal steering of the own ship $u_0^*(t)$, equivalent for the current position $p(t)$ to the optimal positional steering $u_0^*(p)$, is determined:

- for the measured position $p(t_k)$ of the steering status at the moment t_k sets of the acceptable strategies $U_j^0[p(t_k)]$ are determined for the encountered objects in relation to the own ship, and the output sets $U_0^{jw}[p(t_k)]$ of the acceptable strategies of the own ship in relation to each one of the encountered objects,
- a pair of vectors u_j^m and u_0^j, is determined in relation to each *j-th* object and then the optimal positional strategy of the own ship $u_0^*(p)$ from the condition:

$$I^* = \min_{u_0 \in U_0 = \bigcap_{j=1}^{m} U_0^j} \left\{ \max_{u_j^m \in U_j} \min_{u_0^j \in U_0^j(u_j)} S_0[x_0(t_k), L_k] \right\} = S_0^*(x_0, L_k) \quad (4)$$

$$S_0[x_0(t), L_k] = \int_{t_0}^{t_{Lk}} u_0(t)\,dt \quad (5)$$

where S_0 refers to the continuous function of the manoeuvring goal of the own ship, characterising the distance of the ship at the initial moment t_0 to the nearest turning point L_k on the reference $p_r(t_k)$ route of the voyage.

The optimal steering of the own ship is calculated at each discrete stage of the ship's movement by applying the SIMPLEX method to solve the problem of the linear programming, assuming the relationship (4) as the goal function and the control constraints (2).

Using the function of *lp – linear programming* from the Optimisation Toolbox Matlab, the positional multi-stage game non-cooperative manoeuvring NPG program has been designed for the determination of the own ship safe trajectory in a collision situation (Lebkowski 2001, Lisowski 2001a, 2008b, Segal 1998).

2.2 *Algorithm of cooperative positional game CPG*

Goal function (4) for cooperative game has the form:

$$I^* = \min_{u_0 \in U_0 = \bigcap_{j=1}^{m} U_0^j} \left\{ \min_{u_j^m \in U_j} \min_{u_0^j \in U_0^j(u_j)} S_0[x_0(t_k), L_k] \right\} = S_0^*(x_0, L_k) \quad (6)$$

2.3 *Algorithm of matrix game MG*

The dynamic game is reduced to a multi-step matrix game of a j number of participants (Lisowski 2001b, 2004a, 2006a, Radzik 2000). The matrix game $\boldsymbol{R} = [r_j(\nu_j, \nu_0)]$ includes the values determined previously on the basis of data taken from an anti-collision system ARPA the value a collision risk r_j with regard to the determined strategies ν_0 of the own ship and those ν_j of the *j-th* encountered objects. The matrix risk contains the same number of columns as the number of participant I (own ship) strategies and the number of lines which correspond to a joint number of participant II (j objects) strategies (Fig. 2).

The value of the risk of the collision r_j is defined as the reference of the current situation of the approach described by the parameters D^j_{min} and T^j_{min}, to the assumed assessment of the situation defined as safe and determined by the safe distance of approach D_s and the safe time T_s – which are necessary to execute a manoeuvre avoiding a collision with consideration actual distance D_j between own ship and encountered *j-th* ship:

$$r_j = \left[w_1 \left(\frac{D^j_{min}}{D_s} \right)^2 + w_2 \left(\frac{T^j_{min}}{T_s} \right)^2 + \left(\frac{D_j}{D_s} \right)^2 \right]^{-\frac{1}{2}} \quad (7)$$

where the weight coefficients (w_1, w_2) are depended on the state visibility at sea, dynamic length and dynamic beam of the ship, kind of water region.

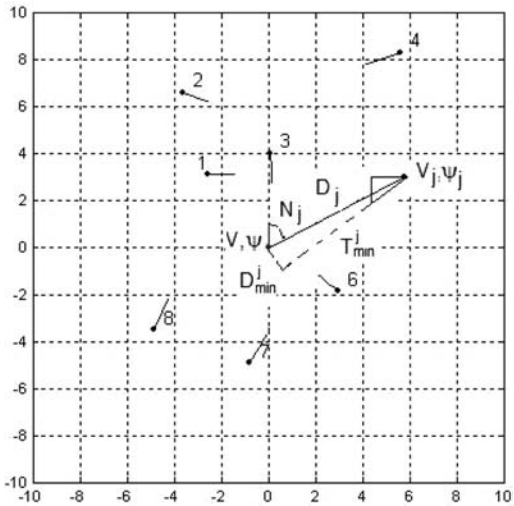

Figure 2. Navigational situation representing the passing of the own ship with the *j-th* object.

The constraints affecting the choice of strategies (ν_0, ν_j) are a result of COLREG recommendations.

Player I may use ν_0 of various pure strategies in a matrix game and player II has ν_j of various pure strategies.

As the game, most frequently, does not have saddle point the state of balance is not guaranteed – there is a lack of pure strategies for both players in the game. The problem of determining an optimal strategy may be reduced to the task of solving dual linear programming problem. Mixed strategy components express the distribution of probability $p_j(\nu_j, \nu_0)$ of using pure strategies by the players. As a result of using the following form for the steering criterion:

$$\left(I_0^j\right)^* = \min_{\nu_0} \max_{\nu_j} r_j \tag{8}$$

the probability matrix $\boldsymbol{P} = [p_j(\nu_j, \nu_0)]$ of using particular pure strategies may be obtained.

The solution for the steering goal is the strategy of the highest probability:

$$\left(u_0^{\nu_0}\right)^* = u_o^{\nu_0}\left\{[p_j(\nu_j, \nu_0)]_{max}\right\} \tag{9}$$

Using the function of *lp – linear programming* from the Optimisation Toolbox Matlab, the matrix multi-step game manoeuvring MG program has been designed for the determination of the own ship safe trajectory in a collision situation (Cichuta 2000).

2.4 *Algorithm of dynamic optimisation DO*

The description of the own ship dynamic allows for the following representation of the state equations in a discrete form:

$$x_{i,k+1} = x_{i,k} + \Delta x_{i,k}(x_i, u_1, u_2) \qquad i = 1, 2, ..., 7 \tag{10}$$

where $x_1 = X_0$, $x_2 = Y_0$, $x_3 = \psi$, $x_4 = \dot{\psi}_{max}$, $x_5 = V$, $x_6 = \dot{V}$, $x_7 = t$, $u_1 = \alpha_r/\alpha_{max}$, $u_2 = n_r/n_{max}$

where $x_1 = X_0$, $x_2 = Y_0$, $x_3 = \psi$, $x_4 = \dot{\psi}_{max}$, $x_5 = V$, $x_6 = \dot{V}$, $x_7 = t$, $u_1 = \alpha_r/\alpha_{max}$, $u_2 = n_r/n_{max}$

The basic criterion for the ship's control is to ensure safe passing of the objects, which is considered in the state constraints:

$$g_j(X_j, Y_j, t) \le 0 \tag{11}$$

This dependence is determined by the area *ship's domain* of the collision hazard and which assumes the form of a circle, parable, ellipse or hexagon (Baba 2001, Lisowski 2000b).

The ships domains may have a permanent or variable shapes generated, for example, by Neural Network Toolbox Matlab. Moreover, a criterion of optimisation is taken into consideration in the form of smallest possible way loss for safe passing of the objects, which, at a constant speed of the own ship, leads to the time-optimal control:

$$I(u_1, u_2) = \int_0^{t_k} x_5\, dt \cong x_5 \int_0^{t_k} dt \rightarrow min \tag{12}$$

Determination of the optimal control of the ship in terms of an adopted control quality index may be performed by applying Bellman's principle of optimisation. The optimal time for the ship to go through k stages is as follows:

$$t_k^* = \min_{u_{1,k-2},\,u_{2,k-2}} \left[t_{k-1}^* + \Delta t_k(x_{1,k}, x_{2,k}, x_{1,k+1}, x_{2,k+1}, x_{5,k})\right] \tag{13}$$

The optimal time for the ship to go through the *k* stages is a function of the system state at the end of the $k-1$ stage and control $(u_{1,k-2}, u_{2,k-2})$ at the $k-2$ stage (Levine 1996).

By going from the first stage to the last one the formula (13) determines the Bellman's functional equation for the process of the ship's control by the alteration of the rudder angle and the rotational speed of the screw propeller (Nise 2008).

The constraints for the state variables and the control values generate the *NEUROCONSTR* procedure in the dynamic optimal control DO program for the determination of the own ship safe trajectory in a collision situation (Skogestad 2005).

2.5 *Algorithm of kinematics optimisation KO*

Goal function (4) for kinematics optimisation has the form:

$$I^* = \min_{u_0 \in U_0 = \bigcap_{j=1}^{m} U_0^j} \left\{S_0[x_0(t_k), L_k]\right\} = S_0^*(x_0, L_k) \tag{14}$$

3 COMPUTER SIMULATION

Computer simulation of NPG, CPG, MG, DO and KO algorithms was carried out in Matlab/Simulink software on an examples of a real navigational situations at sea of passing *j* encountered objects (Pachciarek 2007, Lisowski 2008c).

3.1 *Situation for $j = 4$ encountered ships*

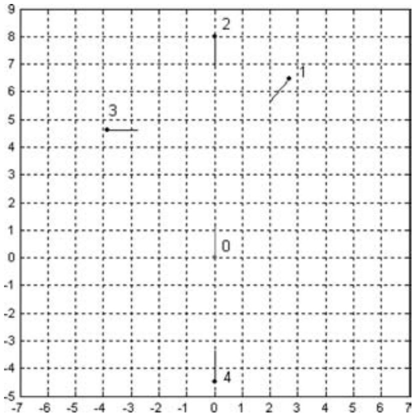

Figure 3. The 6 minute speed vectors of own and 4 encountered ships in situation in Kattegat Strait.

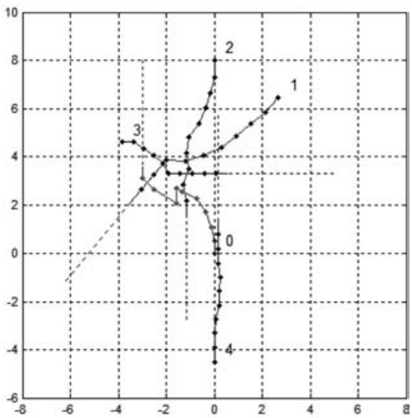

Figure 4. The safe trajectory of own ship for NPG algorithm in good visibility $D_s = 1$ nm in situation of passing $j = 4$ encountered ships, $r(t_k) = 0$, $d(t_k) = 2.99\,nm$.

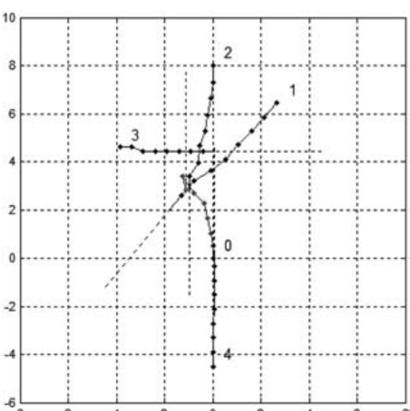

Figure 5. The safe trajectory of own ship for CPG algorithm in good visibility $D_s = 1$ nm in situation of passing $j = 4$ encountered ships, $r(t_k) = 0$, $d(t_k) = 1.10\,nm$.

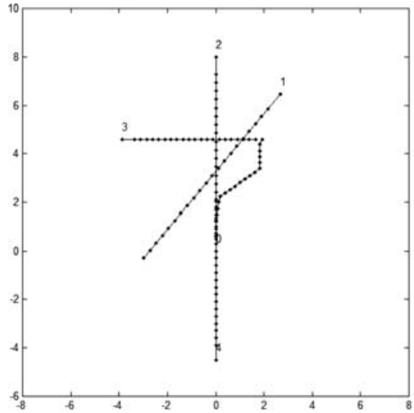

Figure 6. The safe trajectory of own ship for MG algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 4$ encountered ships, $r(t_k) = 0$, $d(t_k) = 0.83\,nm$.

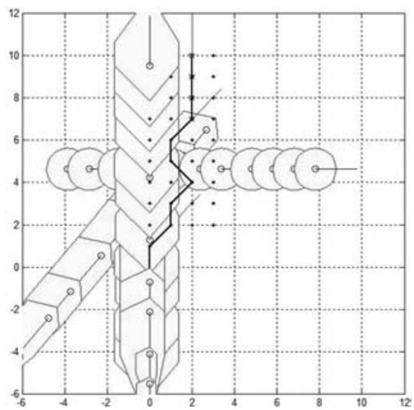

Figure 7. The safe trajectory of own ship for DO algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 4$ encountered ships, $t^*_K = 1.16\,h$.

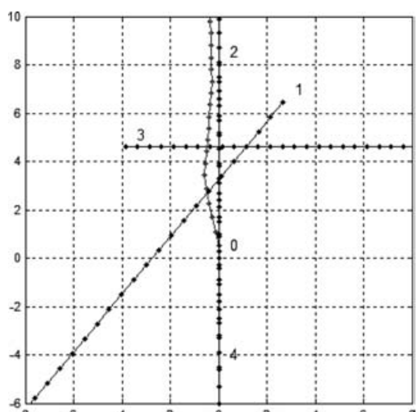

Figure 8. The safe trajectory of own ship for KO algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 4$ encountered ships, $r(t_k) = 0$, $d(t_k) = 0.38\,nm$.

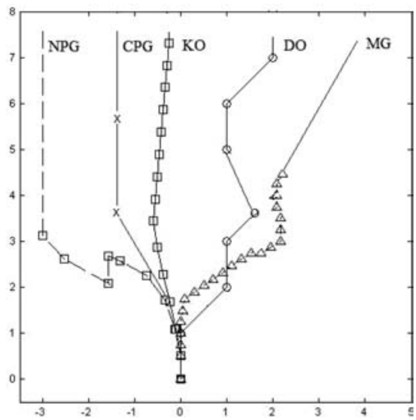

Figure 9. The comparison of own ship safe trajectories in good visibility $D_s = 1\,nm$ in situation of passing $j = 4$ encountered ships.

3.2 *Situation for $j = 8$ encountered ships*

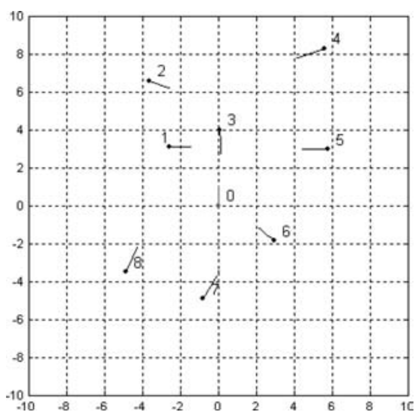

Figure 10. The 6 minute speed vectors of own and 8 encountered ships in situation in Kattegat Strait.

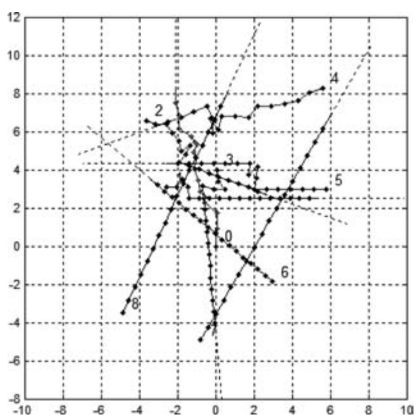

Figure 11. The safe trajectory of own ship for NPG algorithm in good visibility $D_s = 1$ nm in situation of passing $j = 8$ encountered ships, $r(t_k) = 0, d(t_k) = 2.10\,nm$.

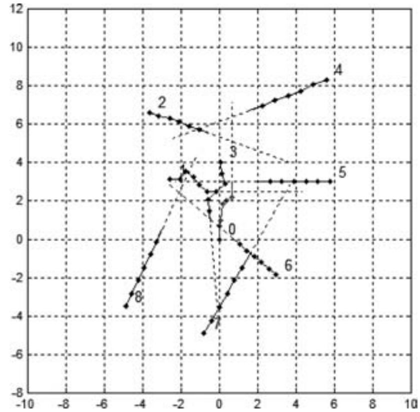

Figure 12. The safe trajectory of own ship for CPG algorithm in good visibility $D_s = 1$ nm in situation of passing $j = 8$ encountered ships, $r(t_k) = 0, d(t_k) = 0.68\,nm$.

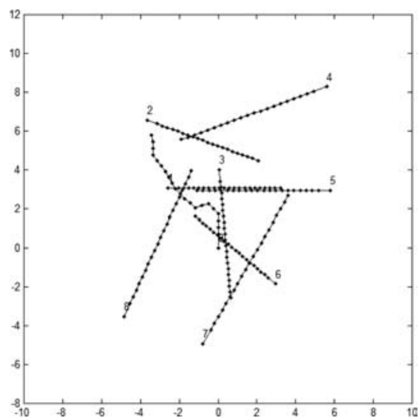

Figure 13. The safe trajectory of own ship for MG algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 8$ encountered ships, $r(t_k) = 0, d(t_k) = 2.74\,nm$.

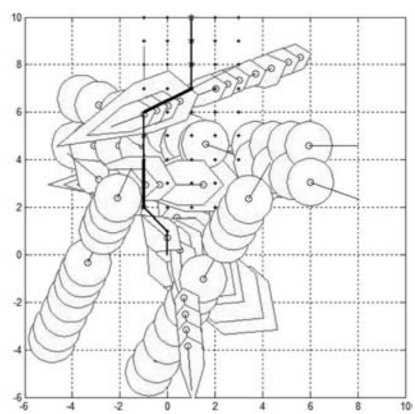

Figure 14. The safe trajectory of own ship for DO algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 8$ encountered ships, $t_K^* = 0.93\,h$.

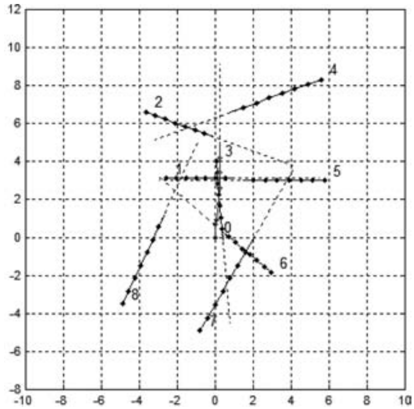

Figure 15. The safe trajectory of own ship for KO algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 8$ encountered ships, $r(t_k) = 0$, $d(t_k) = 0.26\,nm$.

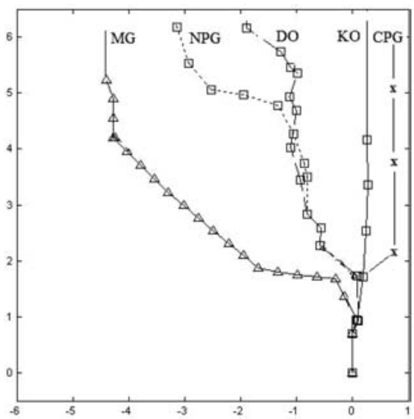

Figure 16. The comparison of own ship safe trajectories in good visibility $D_s = 1\,nm$ in situation of passing $j = 8$ encountered ships.

3.3 *Situation for $j = 19$ encountered ships*

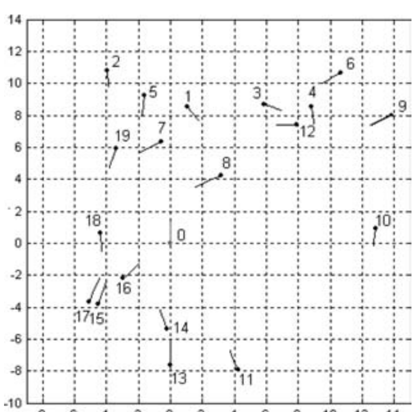

Figure 17. The 6 minute speed vectors of own and 19 encountered ships in situation on the North Sea.

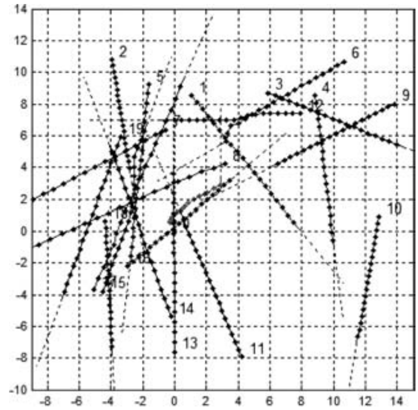

Figure 18. The safe trajectory of own ship for NPG algorithm in good visibility $D_s = 1$ nm in situation of passing $j = 19$ encountered ships, $r(t_k) = 0$, $d(t_k) = 2.92\,nm$.

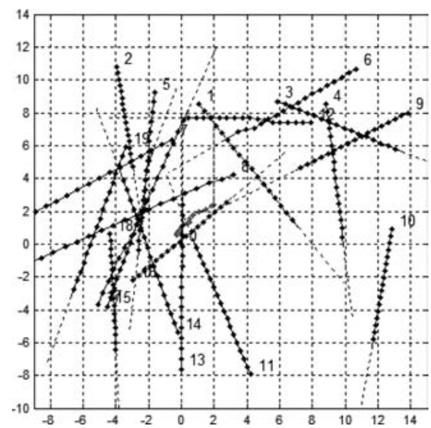

Figure 19. The safe trajectory of own ship for CPG algorithm in good visibility $D_s = 1$ nm in situation of passing $j = 19$ encountered ships, $r(t_k) = 0$, $d(t_k) = 1.95\,nm$.

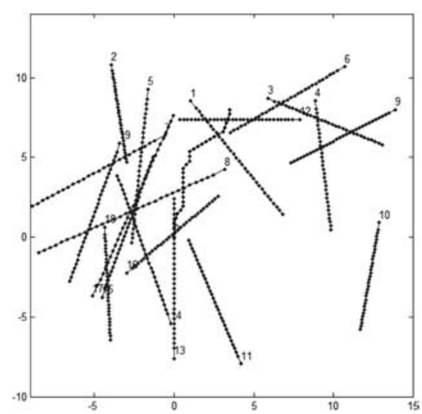

Figure 20. The safe trajectory of own ship for MG algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 19$ encountered ships, $r(t_k) = 0$, $d(t_k) = 3.81\,nm$.

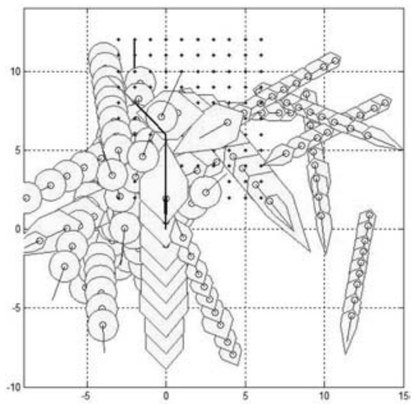

Figure 21. The safe trajectory of own ship for DO algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 19$ encountered ships, $t_K^* = 1.10\,h$.

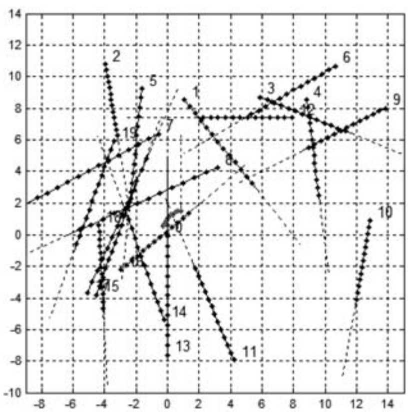

Figure 22. The safe trajectory of own ship for KO algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 19$ encountered ships, $r(t_k) = 0, d(t_k) = 0.84\,nm$.

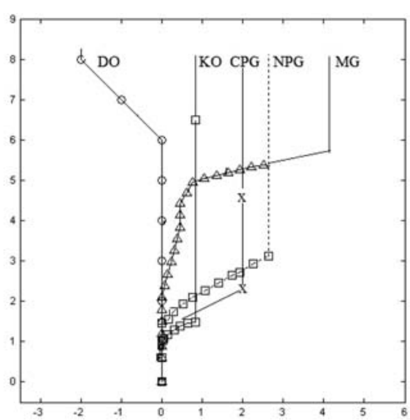

Figure 23. The comparison of own ship safe trajectories in good visibility $D_s = 1\,nm$ in situation of passing $j = 19$ encountered ships.

3.4 *Situation for j = 47 encountered ships*

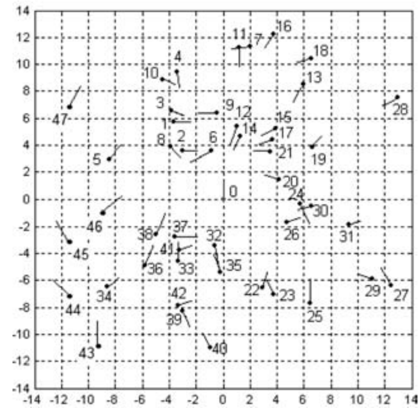

Figure 24. The 6 minute speed vectors of own and 47 encountered ships in situation in the English Channel.

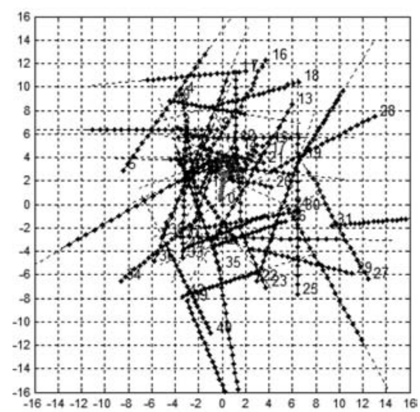

Figure 25. The safe trajectory of own ship for NPG algorithm in good visibility $D_s = 1$ nm in situation of passing $j = 47$ encountered ships, $r(t_k) = 0, d(t_k) = 0.11\,nm$.

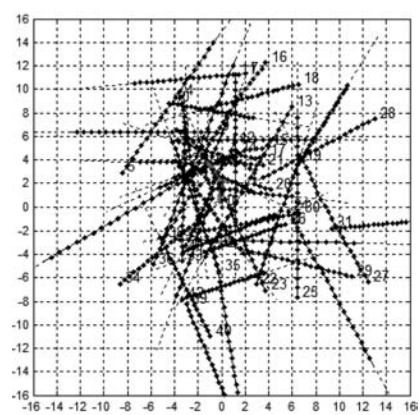

Figure 26. The safe trajectory of own ship for CPG algorithm in good visibility $D_s = 1$ nm in situation of passing $j = 47$ encountered ships, $r(t_k) = 0, d(t_k) = 1.17\,nm$.

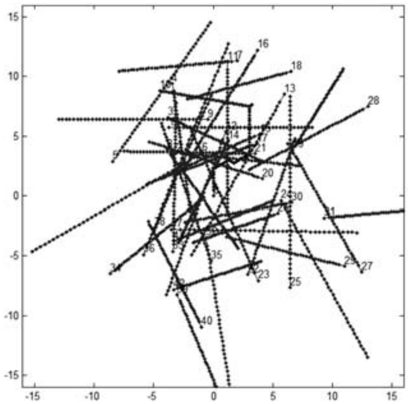

Figure 27. The safe trajectory of own ship for MG algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 47$ encountered ships, $r(t_k) = 0, d(t_k) = 3.83\,nm$.

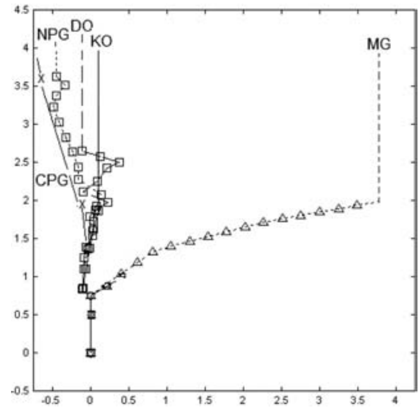

Figure 30. The comparison of own ship safe trajectories in good visibility $D_s = 1\,nm$ in situation of passing $j = 47$ encountered ships.

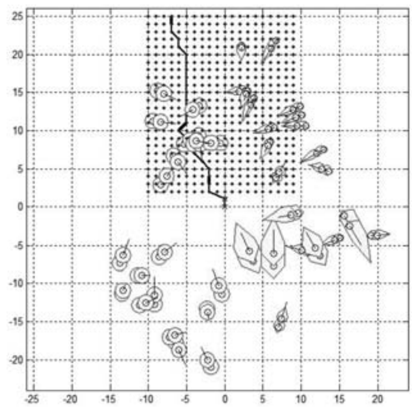

Figure 28. The safe trajectory of own ship for DO algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 47$ encountered ships, $t_K^* = 3.03\,h$.

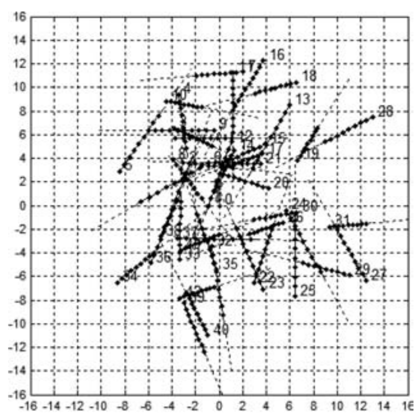

Figure 29. The safe trajectory of own ship for KO algorithm in good visibility $D_s = 1\,nm$ in situation of passing $j = 47$ encountered ships, $r(t_k) = 0, d(t_k) = 0.11\,nm$.

4 CONCLUSION

In order to ensure safe navigation the ships are obliged to observe legal requirements contained in the COLREG Rules. However, these Rules refer exclusively to two ships under good visibility conditions, in case of restricted visibility the Rules provide only recommendations of general nature and they are unable to consider all necessary conditions of the real process.

Therefore the real process of the ships passing exercises occurs under the conditions of indefiniteness and conflict accompanied by an imprecise co-operation among the ships in the light of the legal regulations.

A necessity to consider simultaneously the strategies of the encountered ships and the dynamic properties of the ships as control objects is a good reason for the application of the differential game model – often called the dynamic game.

The control methods considered in this paper are, in a certain sense, formal models for the thinking processes of a navigating officer steering of own ships. Therefore they may be applied in the construction of both appropriate training simulators at the maritime training centre and also for various options of the basic module of the ARPA anti-collision system.

The application of approximate models of the dynamic game to synthesis of optimal control allows the determination of safe trajectory in situations of passing a greater number of met objects as sequence of course and speed manoeuvres.

The algorithms NPG and CPG determine game and safe trajectory of the ship with relation to of all objects and permits to take into account the degree of their cooperation.

The algorithm MG determines game and safe trajectory of the ship with relation to of the object of most dangerous.

The algorithms DO and KO determine the optimal and safe trajectory of the ship most nearing to the received trajectory from the training simulator ARPA.

The developed algorithms takes also into consideration the Rules of the COLREG Rules and the advance time of the manoeuvre approximating the ship's dynamic properties and evaluates the final deviation of the real trajectory from the reference value.

These algorithms can be used for computer supporting of navigator safe manoeuvring decision in a collision situations using information from ARPA anti-collision radar system.

The sensitivity of the final game payment:

– is least relative to the sampling period of the trajectory and advance time manoeuvre,
– most is relative to changes of the own and met ships speed and course,
– it grows with the degree of playing character of the control process and with the quantity of admissible strategies.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

12.3
A numerical study of combined natural and Marangoni convection in a square cavity

K. Cicek & A. Cihat Baytas
Istanbul Technical University, Tuzla, Istanbul, Turkey

ABSTRACT: Through the aim of this study, the effects of combined buoyancy-driven flows and thermo capillary flows, which are emerged from temperature differences, on fluid flow and heat transfer numerically investigated with differentially heated side walls in a free surface square cavity. The study has been accomplished with three milestones to achieve the right solutions. For every milestone Navier-Stokes, continuity and energy equations are discretized by using finite volume method and grids with 52×52 control volumes. Results are presented $\mathrm{Pr} = 1$, $\mathrm{Pr} = 7$ and $\mathrm{Pr} = 100$. The effect of positive and negative Marangoni number on fluid flow and heat transfer at different Rayleigh number are considered and discussed.

NOMENCLATURE

cp: specific heat at a constant pressure J/(kg-K)
D: height of cavity, m
g: gravitational acceleration, m^2/s
h: convection heat transfer coefficient, $W/(m^2\text{-}K)$
k: thermal conductivity, W/(m-K)
p: pressure, N/m^2
q'': heat flux, W/m^2
t: time, s
T: temperature, K
u: horizontal velocity, m/s
U: dimensionless horizontal velocity
v: vertical velocity, m/s
V: dimensionless vertical velocity
x,y: coordinates, m
X: dimensionless horizontal coordinate
Y: dimensionless vertical coordinate
ΔT: temperature difference (T_H-T_C)
α: thermal diffusivity, m^2/s
β: thermal expansion coefficient, 1/K
θ: dimensionless temperature
μ: dynamic viscosity, kg/(m-s)
ν: kinematics viscosity, m^2/s
ρ: density, kg/m^3
σ: surface tension, N/m
σT: temperature coefficient of surface tension, N/(m-K)
τ: dimensionless time
ψ: stream function, m^2/s
Ψ: dimensionless stream function
ω: vorticity, 1/s
Ω: dimensionless vorticity

Dimensionless Numbers
Pr: Prandtl number
Ra: Rayleigh number
Ma: Marangoni number
Nu: Nusselt number
Nu: Average Nusselt number
Pe: Peclet number

Subscripts
H: hot
C: cold
l: local

1 INTRODUCTION

From its modest origins, maritime transportation has always been the dominant support of global trade. Therewithal, the importance of maritime transportation increases in parallel with technologic evolutions, technical improvements and economic development of countries. High level of economic growth, industrialization, technological evolutions and urbanization for developed countries result in an increase in energy demand. It was determined that in 2005, 86% of primary energy demand in the world supplied from petroleum and derivatives. Therefore, maritime transportation is the most important transportation mode for transferring of petroleum and its derivatives to procure energy demand. With the current data illustrated that transportation of fossil fuels by seaway reached approximately twenty seven billion tons in the year 2007 (UNCTAD, 2007).

Increase in the volume of carriage of petroleum and its derivatives with maritime transportation have increased the risk of the maritime accidents such as oil spill, collision, grounding of ships that threaten to environment, ecosystems, and aquatic life. For this reason many academic researches and studies are directly focused out on prevention of pollution of marine environment with exploring fluid mechanics and heat transfer events in cargo tanks of ships such as

Grau et al. 2004, Oro et al. 2006, Pallares et al. 2004, Segerre-Perez et al. 2007.

The main aim of present study is to shed light on fluid flow and heat transfer in cargo tank of ships. The present work is a numerical study natural convection due to the temperature difference between left and right wall and Marangoni convection due to the free surface effect in a two-dimensional square cavity. Natural convection is induced by the difference in temperature between vertical walls, and it is represented by the Rayleigh number (Ra). Marangoni convection flow directly related to the surface tension gradient with respect to temperature which acts as a force applied to the free surface of the cavity, and it is represented by the Marangoni number (Ma). The presence of free surface can not only alter the flow field and heat transfer but also prove to have an impact on the process because of surface tension variations (Behnia, Stella, Guj 1995; Bergman & Ramadhyani 1986; Smith & Davis 1983).

The study is conducted numerically under the assumption of steady laminar flow with three milestones. In the first milestone, natural convection in a two-dimensional square cavity has been investigated with the left vertical wall is a constant temperature T_h, the right wall is constant T_c and all other walls are assumed adiabatic. In the second milestone, combined natural and Marangoni convection in a two-dimensional square cavity with a top free surface has been investigated with the left vertical wall is a constant temperature T_h, the right wall is constant T_c, and all other walls are adiabatic. In the third and last milestone combined natural and Marangoni convection in a two-dimensional square cavity with a top free surface has been investigated with the left vertical wall is a constant temperature T_c, the right and bottom wall is constant T_c, whilst top surface is adiabatic. For the second and third milestones, the top surface deformation and interactions with the gaseous phase are neglected. In every three steps, the Navier-Stokes, continuity and energy equations are solved using finite volume method and grids with 52×52 control volumes. Results are presented $Pr = 7$ for first and second milestones, $Pr = 100$ for third milestone. The effect of positive and negative Marangoni number on the fluid flow and heat transfer at different Rayleigh numbers are considered and discussed.

2 MATHEMATICAL MODEL

A schematic diagram of every milestone shows in Figure 1, Figure 2 and Figure 3 respectively.

In Figure 1, it is assumed that the left vertical wall of the cavity is a constant value T_H. The right vertical wall is held at a constant temperature T_C, while the horizontal walls are adiabatic. In Figure 2, it is assumed that the left vertical wall of the cavity is a constant value T_H. The right vertical wall is held at a constant temperature T_C, top horizontal wall is a free surface and adiabatic and bottom horizontal wall is adiabatic. In Figure 3, cargo tank is modeled to investigate fluid motion and heat transfer in tank. In Figure 3, it is assumed that the left vertical wall of the cavity is a constant value T_H. The right vertical wall and bottom horizontal walls are held at a constant temperature T_C, while the top horizontal wall is a free surface and adiabatic.

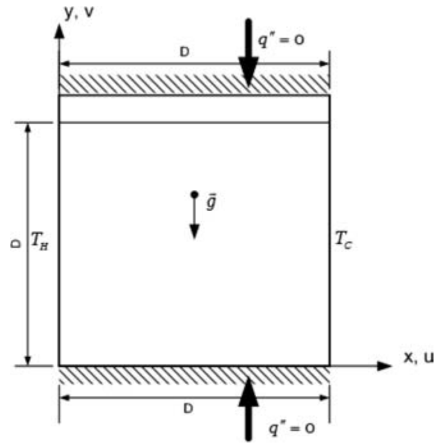

Figure 1. Schematic diagram of the physical model and coordinate system of first milestone.

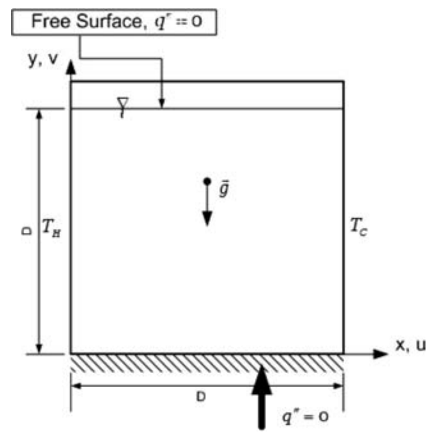

Figure 2. Schematic diagram of the physical model and coordinate system of second milestone.

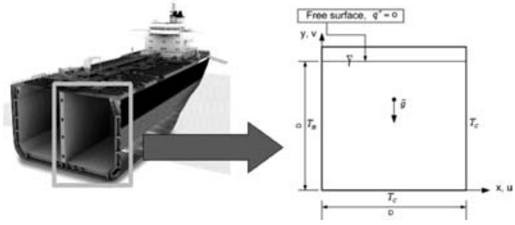

Figure 3. Schematic diagram of the physical model and coordinate system of third milestone.

To model the liquid motion in cavity, we use the conservation equation for mass, momentum and energy for two-dimensional, steady and laminar flow. All the physical properties of fluid, μ, k and c_p are considered constant except density, in buoyancy term, which obeys Boussinesq approximation. In the energy conservation, we neglect the effect of compressibility and viscous dissipation. With these assumptions the continuity, momentum and energy equations can be written as;

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\rho\frac{dv}{dt}=\rho g-\nabla P+\mu\nabla^2 v \tag{2}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right] \tag{3}$$

Introducing the vorticity w as;

$$w=\nabla\times v \tag{4}$$

to get vorticity transport equation by taking the curl of momentum equation to eliminates the ∇P term, the momentum equation can be rewritten in terms of the vorticity defined above as;

$$\frac{\partial \omega}{\partial t}+u\frac{\partial \omega}{\partial x}+v\frac{\partial \omega}{\partial y}=\nu\nabla^2\omega+g\beta\frac{\partial T}{\partial x} \tag{5}$$

The stream function (ψ) for two dimensional problem is defined such that;

$$v=\nabla\times\psi \tag{6}$$

the vorticity transport equation can be obtained from Eqs. (5) and (6), which further gives;

$$\omega=-\nabla^2\psi \tag{7}$$

The governing equations are converted into the non-dimensional form by defining the non-dimensional variables:

$$X=\frac{x}{D},\ Y=\frac{y}{D},\ U=\frac{uD}{\alpha},\ V=\frac{vD}{\alpha},\ \Omega=\frac{\omega D^2}{\alpha}$$
$$\Psi=\frac{\psi}{\alpha},\ \theta=\frac{T-T_c}{\Delta T},\ \tau=\frac{t\alpha}{D^2},\ Ra=\frac{g\beta\Delta T D^3}{\nu\alpha},\ \Pr=\frac{\nu}{\alpha} \tag{8}$$

Based on these non-dimensional variables, the governing equations are obtained as follow;

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \tag{9}$$

$$\frac{\partial \Omega}{\partial \tau}+U\cdot\frac{\partial \Omega}{\partial X}+V\cdot\frac{\partial \Omega}{\partial Y}=\Pr\cdot\left[\frac{\partial^2\Omega}{\partial X^2}+\frac{\partial^2\Omega}{\partial Y^2}\right]+Ra\cdot\Pr\cdot\frac{\partial\theta}{\partial X} \tag{10}$$

$$\frac{\partial \theta}{\partial \tau}+U\cdot\frac{\partial \theta}{\partial X}+V\cdot\frac{\partial \theta}{\partial Y}=\nabla^2\theta \tag{11}$$

$$-\Omega=\nabla^2\Psi \tag{12}$$

$$U=\frac{\partial\Psi}{\partial Y},\ V=-\frac{\partial\Psi}{\partial X} \tag{13}$$

Other physical quantities of interest in the present study are the average and local Nusselt numbers for the hot and cold walls; these variables are defined respectively as;

$$Nu_{l(hot)}=-\left.\frac{\partial\theta}{\partial X}\right|_{x=0},\ Nu_{l(cold)}=-\left.\frac{\partial\theta}{\partial X}\right|_{x=D} \tag{14}$$

$$\overline{Nu}=-\int_0^1\frac{\partial\theta}{\partial X}dY=-\int_0^1 Nu_l dY \tag{15}$$

3 INITIAL & BOUNDARY CONDITIONS

In order to obtain results of the conservation equations we define initial and boundary conditions. For each milestone initial conditions are at $\tau=0$;

$$U=V=\theta=\Psi=\Omega=0$$

But it is necessary to define boundary conditions of each milestone separately. In first milestone the boundary conditions are at $\tau\geq 0$;

$$\mathrm{X}=0,\ 0\leq Y\leq 1,\ U=V=\Psi=0\ \&\ \theta=1 \tag{16a}$$

$$\mathrm{X}=1 \text{ ve } 0\leq Y\leq 1 \text{ de } U=V=\Psi=0\ \&\ \theta=0 \tag{16b}$$

$$\mathrm{Y}=0,\ 0\leq X\leq 1,\ U=V=\Psi=0\ \&\ \frac{\partial\theta}{\partial Y}=0 \tag{16c}$$

$$\mathrm{Y}=1 \text{ ve } 0\leq X\leq 1 \text{ de } U=V=\Psi=0\ \&\ \frac{\partial\theta}{\partial Y}=0 \tag{16d}$$

Also it is necessary to define non-dimensional vorticity boundary conditions and with the help of Eqs. (4) the boundary conditions can be obtained as for vertical walls;

$$\Omega=-\frac{\partial^2\Psi}{\partial X^2} \tag{16e}$$

and for horizontal walls;

$$\Omega=-\frac{\partial^2\Psi}{\partial Y^2} \tag{16f}$$

In the second and third milestones free surface condition must be taken in consideration. The presence of this type of boundary condition can not only alter the flow field and heat transfer characteristics but may also prove to have an impact on the process because of surface tension variations. (Smith & Davis 1983; Bergman & Ramadhyani 1986). In general, for most liquids there is a variation of surface tension with temperature. As a result, the interface between air and liquid which is subjected to a temperature gradient can initiate a bulk flow due to surface tension variations. This flow which is due to a temperature gradient applied normally to the free surface is known as Marangoni convection (Behnia et al 1995). After that explanation, the boundary condition at a free surface can be written as,

$$\left.\frac{\partial u}{\partial y}\right|_{y=D} = \frac{1}{\mu}\cdot\frac{\partial\sigma}{\partial T}\cdot\left.\frac{\partial T}{\partial x}\right|_{y=D} \tag{17}$$

Based on non-dimensional variables expressed in Eqs (8), Eqs 17 are obtained as follow;

$$\frac{\partial U}{\partial Y} = Ma\frac{\partial\theta}{\partial X} \tag{18}$$

$$Ma = -\frac{d\sigma}{dT}\frac{\Delta TD}{\mu\alpha},\ \ \frac{d\sigma}{dT} = \sigma_T$$

Eqs. (18) can be rearranged with the help of

$$U = \frac{\partial\Psi}{\partial Y},\ V = -\frac{\partial\Psi}{\partial X}$$

and obtained as follow;

$$\frac{\partial^2\Psi}{\partial Y^2} = Ma\frac{\partial\theta}{\partial X} \tag{19}$$

This boundary condition applied to a vorticity boundary condition for top horizontal wall as follow;

$$\Omega = -\frac{\partial^2\Psi}{\partial Y^2} = -Ma\frac{\partial\theta}{\partial X} \tag{20}$$

In the second milestone initial and boundary conditions are same with the first milestone except top horizontal wall (free surface condition).

In the third milestone initial and boundary conditions are same with the second milestone except bottom horizontal wall. In this milestone the bottom wall is held to a constant temperature T_c. For this reason the boundary condition for bottom wall is defined as follow,

$$Y = 0, 0 \le X \le 1, U = V = \Psi = 0\ \&\ \theta = 0 \tag{21}$$

4 SOLUTION PROCEDURE

The differential equations, represented by equations (9) to (11), together with respect boundary conditions for every milestone, equations are (16), (20) and (21), are solved using the fine volume method described in Patankar (1980). In this method solution domain is divided into small finite control volumes. The differential equations are integrated into each of those control volumes. From this integration there were algebraic equations which, when solved simultaneously or separately, supplied velocity, stream function, vorticity and temperature components. A power-law scheme is adopted for the convection-diffusion formulation (Patankar 1980).

The discretization equations are solved iteratively, using the line by line method known as Thomas algorithm or TDMA (tridiagonal matrix algorithm). An over relaxation parameter of 1.85 was used in order to obtain stable convergence for the solution of vorticity transport and energy equations.

In order to assess the accuracy of our numerical procedure for every milestone, we have tested our algorithm based on the grid size (42×42) for the first milestone with the work of Davis (1983a), Davis (1983b) and Hortman and Peric (1990), for the second milestone we have tested our algorithm based on the grid sizes (52×52) with the work of Behnia et al (1995).

Grid independence tests were conducted for all the configurations studied in this work. Three different grid size (42×42, 52×52, 62×62) were used and average Nusselt numbers are compared for different grid size. Because of the small differences between 52×52 and 62×62 grids, 52×52 grid was chosen for second and third milestones. For the first milestone 42×42 grid was chosen because of achieve effective benchmark with the work of Davis (1983a), Davis (1983b) and Hortman and Peric (1990). The numerical solution is considered to be converged when the maximum convergence criteria was smaller than 10^{-7}

5 NUMERICAL RESULTS AND DISCUSSION

In Figure 4 illustrate the stream function and isotherm contours of first milestone numerical results for various $Ra = 10^3$ and 10^5 and $Pr = 1$. In general, fluid circulation is strongly dependent on Rayleigh number as we have seen in Figure 4a and 4b. Change in the values of Ra has its influence on the stream lines and isotherms. The centre of circulation pattern moved towards to hot (left) wall of the cavity. Streamlines pattern shows that there is a strong upward flow near the hot wall side and downward flow near the cold wall.

In Figure 5–7 illustrate the stream function and isotherm contours of second milestone numerical results for $Ra = 0$ and 10^4, $Ma = \pm 10^3$ and $Pr = 7$.

In general, fluid circulation is strongly dependent on both Rayleigh number and Marangoni number as we have seen in Figure 5–7. Change in the values of Ra and Ma have influence on the stream lines and isotherms. In Figure 5 only the effects of surface tension are present, the Rayleigh number being set to zero. The flow is driven due to effect of velocity gradients on the top surface. In Figure 6 it is seen that the effect of buoyancy on the flow field is added to the positive Marangoni one. So the flow structure is still constituted by a single large main circulation. Due to the effect of buoyancy forces that are distributed in the bulk of the cavity the main vortex is stronger than in Figure 5 and encompasses almost completely the entire flow domain. For positive Ma there is a strong thermal boundary layer located close to the upper-right corner due to the effect of Marangoni convection in the vicinity of the free surface. In Figure 7, due to the

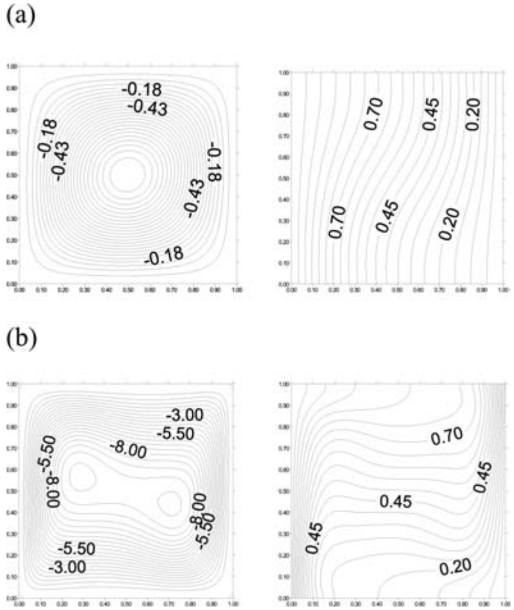

Figure 4. Stream lines and isotherm contours for (a) $\mathrm{Ra}=10^3$, (b) $\mathrm{Ra}=10^5$.

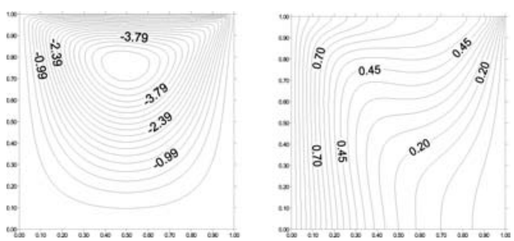

Figure 5. Stream lines and isotherm contours for $\mathrm{Ra}=0$, $\mathrm{Ma}=10^3$.

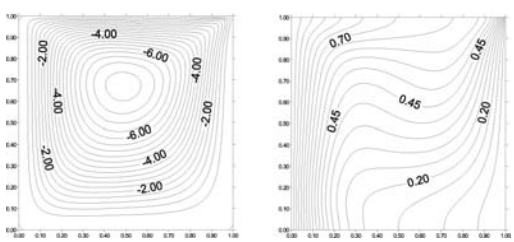

Figure 6. Stream lines and isotherm contours for $\mathrm{Ra}=10^4$, $\mathrm{Ma}=10^3$.

negative value of Marangoni number, there is an opposition of effects between buoyancy and surface tension. For this reason, it is possible to clearly distinguish the effect of the two different contributions. In this case, it is clearly evident how the flow is strongly divided into two regions; the upper one where the motion is induced by surface tension and the lower one driven by buoyancy. Also in Figure 7 isotherm contours shows that the negative Ma causes a strong penetration of hot

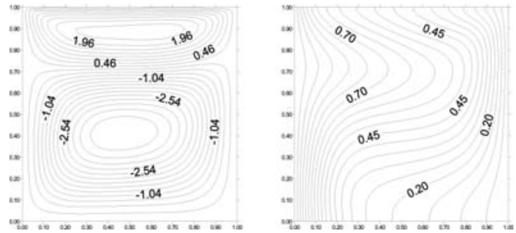

Figure 7. Stream lines and isotherm contours for $\mathrm{Ra}=10^4$, $\mathrm{Ma}=-10^3$.

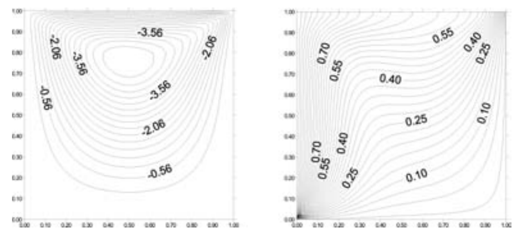

Figure 8. Stream lines and isotherm contours for $\mathrm{Ra}=0$, $\mathrm{Ma}=10^3$.

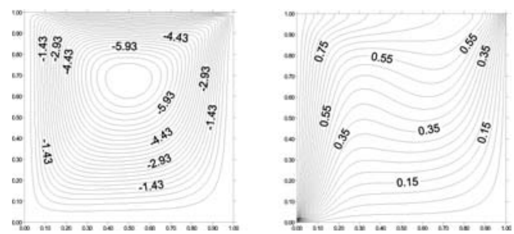

Figure 9. Stream lines and isotherm contours for $\mathrm{Ra}=10^4$, $\mathrm{Ma}=10^3$.

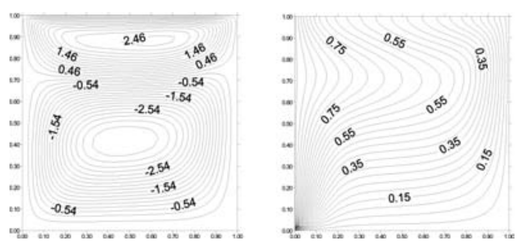

Figure 10. Stream lines and isotherm contours for $\mathrm{Ra}=10^4$, $\mathrm{Ma}=-10^3$.

fluid in the centre of the cavity due to the combined effect of the two counter-rotating recirculation.

In Figure 8–10 illustrate the stream function and isotherm contours of third and last milestone numerical results for $\mathrm{Ra}=0$ and 10^4, $\mathrm{Ma}=\pm 10^3$ and $\mathrm{Pr}=100$.

The bottom wall which is held at a constant temperature T_C doesn't make any changes on stream line contours but have influence on the isotherm contours. As a result there is a strong boundary layer located close to lower-left corner. In Figure 8–10 stream lines contours don't show any difference but isotherm contours with the influence of bottom wall show significance varieties.

6 CONCLUSION

This study try to shed light on fluid flow and heat transfer in cargo tank of ships with investigating of combined natural and Marangoni convection in a liquid.

For the case of positive Marangoni number the fluid structure is mainly constituted by a dominant core vortex structure which becomes stronger as either of the Rayleigh and Marangoni numbers are increased.

More complex and interesting is the flow structure for negative values of Marangoni numbers. In this case, the fluid is stratified and flow filed is clearly divided into two separate regions where the motion is driven by Marangoni (upper region) and buoyancy (lower region) respectively.

Also for the bottom wall at a constant temperature T_c, it is shown that there is a strong thermal boundary layer is formed at the lower-left corner. It is clearly evident of lower-left corner is a strong heat loss point.

Consequently, Marangoni number is as important parameter as Rayleigh number for fluid motion and dispersion of temperature in cavity with free surface and for positive and negative values it changes both stream lines and isotherms contours dispersion in the cavity.

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12.4
An application of mathematical theory of evidence in navigation

W. Filipowicz
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: Plenty of various quality data are available to the officer of watch. The data of various qualities comes from different navigational aids. This kind of data creates new challenge regarding information association. The challenge is met by Mathematical Theory of Evidence. The theory delivers methods enabling combination of various sources of data. Results of association have informative context increased. Associated data enable the navigator to refine his position and his status regarding dangerous places. The procedure involves uncertainty, ambiguity and vague evidence. Imprecise and incomplete evidence can be combined using extended Dempster-Shafer reasoning scheme.

1 INTRODUCTION

There are stochastic and epistemic uncertainties distinguished. Stochastic also called aleatory uncertainty reflects unknown, usually unpredictable behaviour of a system. The system behaves in stochastic way when its states are random ones. They can be identified based on traditional probability theory. In maritime traffic engineering attempt to find deviation from intended track is related to the aleatory uncertainty.

Shortage of knowledge or incomplete evidence creates another kind of uncertainty. Epistemic or subjective uncertainty results from insufficient or vague evidence. Question of identity of new spotted object refers to this sort of uncertainty. It is quite often when observer at monitoring station spots new radar mark and tries to find out what vessel this could be. Usually there is some evidence available, for example radar echo signature and estimate of speed can be helpful. Modern AIS technology transfers data useful in identification. Problem was discussed by the author in his previous papers (Filipowicz 2007 & Filipowicz 2008).). Navigational aids deliver plenty of data used for position fixing. The quality of data is different and depends on many factors. Such imprecise and sometimes incomplete data are further combined for position refinement. Quantifying navigational status regarding an obstacle is crucial from safety standards point of view.

In classical probability theory the knowledge of probability of an event can be used to calculate likelihood of the contrary statement. In this approach if one navigational aid indicates position within certain area with probability of 0.6, that mean that navigator believes that he is outside the area with the probability of 0.4. The theory also requires that data regarding probability of all considered events is at disposal. The theory is limited in its ability when dealing with epistemic uncertainty.

Mathematical Theory of Evidence (MTE for short) is more flexible in this respect. MTE is a theory (initiated by Dempster & Shafer) based on belief and plausibility functions and scheme of reasoning in order to combine separate pieces of evidence to calculate the probability of an event. Contrary to probability theory it enables modelling knowledge and ignorance. Evidence can be combined therefore even partial knowledge associated with less meaningful facts may end up in valuable conclusions. Combining evidence leads to data enrichment and improved probability judgments can be obtained for each considered hypothesis. Fundamental for MTE is Dempster-Shafer scheme of reasoning initially intended for crisp values. New extensions to cope with imprecision are also available since it is often that to obtain precise figures is infeasible. Imprecision is expressed as interval values or fuzzy figures. In the paper and elsewhere fuzzy values are considered as a set of intervals given for selected possibility levels.

Problem of position refinement that involves epistemic uncertainty could be defined as below.

Given:

- navigation aids indicating different positions, different distances from an obstacle
- each aid has reliability and accuracy characteristic assigned to it
- linguistic terms referring to close, sufficient and safe distances are available as membership functions

Question:

- what is credibility that the real distance to the obstacle is safe one?

First part of the paper is devoted to basic probability assignment. Then necessity to deal with imprecision is depicted. Further on interval values are introduced and belief structure defined. Short description of Dempster-Shafer method is also included. Last part of the paper deals with identification of navigational status referring to an obstacle. Two navigational aids are considered. Their indications are combined in order to quantify distance from certain shallow water area.

2 PROBABILITY ASSIGNMENT

Frame of discernment in Mathematical Theory of Evidence consists of possible events. Events are understood very widely. Examples of events that are of interest in navigation could be: route taken by a spotted vessel, position fixing based on an electronic aid, attempt to refine unidentified object etc. Events are considered as atomic or structured ones. Considering limited set of objects as a single entity means dealing with molecular or structured event. For example new spotted object must be large container carrier or medium bulk vessel because no other traffic is expected within the area. It is assumed that in case of structured event all constituents are equally possible.

Let us consider example on reasoning which of possible and treated as equivalent routes r_1 or r_2 will be taken by the vessel shown at figure 1. The frame of discernment embraces three events $\Omega = (\{r_1\}, \{r_2\}, \{r_1, r_2\})$. First event is related to route r_1 as possibly taken by the vessel, selecting route r2 means occurrence of the second event. Third molecular event expresses uncertainty, it constituents r_1 or r_2 are assumed to be equally possible.

Some evidence supporting reasoning on intended ship's itinerary is assumed. Recorded cases with southwest bound vessels of similar tonnage were examined. For all *n* stored cases *x* out of the all have chosen route r_1. Appropriate masses related to each of the events can be calculated according to formula (1). Assuming that data stored in traffic related database gives

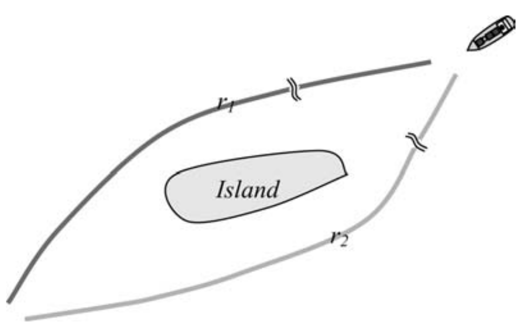

Figure 1. Intended route forecast problem involves three events: taking route r_1, taking r_2 and joint r_1 or r_2.

$x = 24$ and $n = 39$ masses of likelihood that this time particular route is taken should be assigned as shown in formula (1)

$$\begin{aligned} m(\{r_1\}) &= \frac{x}{n+1} = 0.600 \\ m(\{r_2\}) &= \frac{n-x}{n+1} = 0.375 \\ m(\{r_1, r_2\}) &= \frac{1}{n+1} = 0.025 \end{aligned} \tag{1}$$

It is easy to find out that all masses sum up to one so probability requirement is satisfied. The theory also requires that: $m(\{r_1, r_2\}) = 1 - m(\{r_1\}) - m(\{r_2\})$. Note that set $\{r_1, r_2\}$ expresses some sort of uncertainty since it reflects that both available routes can be taken with the same credibility level.

Let us again consider example on guessing which of routes r_1 or r_2 will be taken by the vessel. This time we assume different evidence supporting reasoning on intended ship's itinerary. We assume that various samples of recorded cases are available. Registered routes for similar ships referred to different weather conditions. Number of records in the samples varied within range of [20, 50]. Data analyses discovered that number of southwest bound ships that have chosen route r_1 was around 70% of all stored cases. The percentage never fell below 60% and did not exceed 80% of the total number. Under these assumptions one is not able to calculate masses of evidence using before presented way of reasoning. The task is seemingly unsolved due to limitation imposed by crisp values. Interval values are to be used instead. Counting all pros and cons and numbers of records in the samples interval-valued masses presents formula (2).

$$\begin{aligned} m(\{r_1\}) &= [m_1^-, m_1^+] = \left[\frac{12}{21}, \frac{40}{51}\right] = [0.571, 0.784] \\ m(\{r_2\}) &= [m_2^-, m_2^+] = \left[\frac{10}{51}, \frac{8}{21}\right] = [0.196, 0.381] \\ m(\{r_1, r_2\}) &= [m_3^-, m_3^+] = \left[\frac{1}{51}, \frac{1}{21}\right] = [0.020, 0.048] \end{aligned} \tag{2}$$

In this case all masses cannot sum up to one so basic probability requirement cannot be satisfied. The approach stipulates that exists a set of sub ranges within defined intervals within which summation to one is observed. More formally conditions 1 and 2 in definition (1) are to be true. Definition (1) refers to interval-valued probability assignment that is also called as interval-valued belief structure.

Definition (1):

Interval-valued masses attributed to respective elements of the frame of discernment, namely: $[m_1^-, m_1^+]$, $[m_2^-, m_2^+], \ldots, [m_n^-, m_n^+]$ define adequate probability assignment if there is a set **m** such that for $m \in \mathbf{m}$ following are satisfied:

- within each interval there is a value: $m_i^- \leq m_i \leq m_i^+$, for each $i \in \{1, \ldots, n\}$
- for all such values: $\sum_{i=1}^{n} m_i = 1$

For example three interval-valued masses the set of legal probability assignment is shown as two dimensional shape in figure 2. Procedure of establishing such shape can also lead to tightening interval bounds since some values may appear as unreachable.

We again consider above example on guessing which of routes r_1 or r_2 will be taken by the vessel using fuzzy approach. We assume that it is experienced radar observer who reasons on intended ship's itinerary. His subjective way of thinking is like this: the vessel is a medium one, visibility is rather good, wind moderate so to his best knowledge it is "likely" the vessel will take route r_1. He also observed quite many similar vessels have taken route r_2 so it is "fairly likely" that this route will be chosen this time. Judging from his experience uncertainty of his opinion is very low. Formal expression of the above statement requires introduction of meaning terms: "likely", "fairly likely" and "very low". All of them are linguistic terms referring to fuzzy reasoning. Such terms are characterized by membership functions.

2.1 *Theoretical membership functions*

Set with elements like: "very unlikely", "unlikely", "fairly likely", "likely", "very likely" and "certain" consists of linguistic terms which human beings use for estimated reasoning. To evaluate uncertainty one can use "very low", "low", "medium", "high", "very high" and "totally uncertain" as the highest term. Both sets contain six elements and membership functions can be used interchangeably depending on the context.

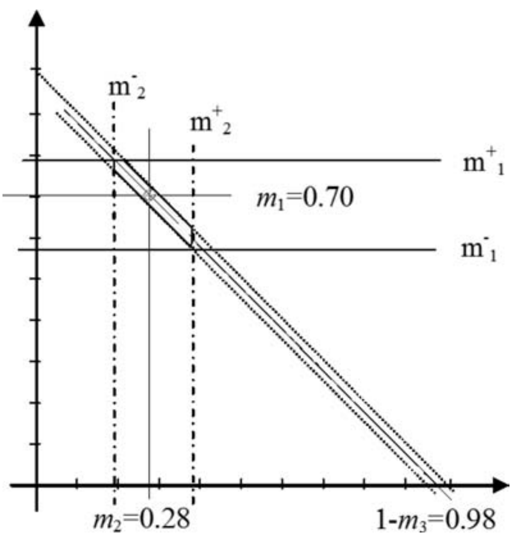

Figure 2. Graphical presentation of the set of valid probability assignment in interval-valued belief structure.

Counting elements from 0 up to $n_c - 1$ one can use formula (3) to calculate normalized and regular fuzzy membership functions. Trapezoid shapes obtained for $w_T = 0.8$ are presented in figure 3 and triangular ones for $w_T = 0$ in figure 4.

$$F_k = \begin{cases} (0, 0, w_T * w, w) & if\ k = 0 \\ ((k-1) * w, k * w - w_T * w, \\ k * w + w_T * w, (k+1) * w) & if\ 0 < k < n_c - 1 \\ (1 - w, 1 - w_T * w, 1, 1) & if\ k = n_c - 1 \end{cases} \quad (3)$$

where:

- $w = \dfrac{1}{n_c - 1}$
- n_c – is a number of selected terms
- $w_T \in [0, 1]$ – is the shape parameter, $w_T = 0$ means that membership function is a triangular one and $w_T = 1$ means rectangular shape.

Formula (4) defines trapezoid fuzzy-valued masses assignment for the third discussed case of probability assignment on expected route taken by the spotted

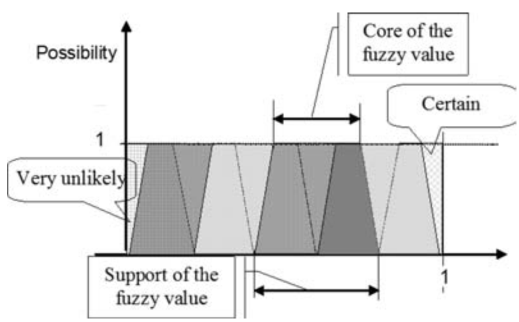

Figure 3. Trapezoid membership functions ($w_T = 0.8$).

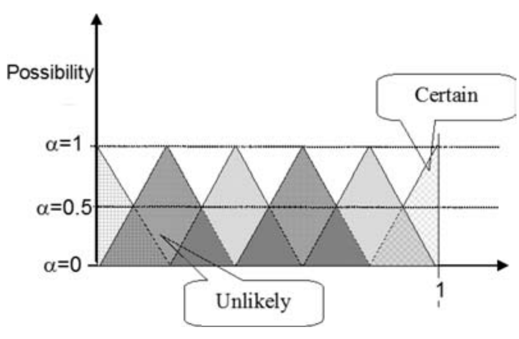

Figure 4. Triangular membership functions expressing six linguistic terms ($w_T = 0$).

Table 1. Combination of two sources of crisp data.

	Source I		
	$m_1(\{s_1\})$ [0.571, 0.784]	$m_1(\{s_2\})$ [0.196, 0.381]	$m_1(\{s_1, s_2\})$ [0.020, 0.048]
$m_2(\{s_1\})$ [0.488, 0.639]	$m_{1-2}(\{s_1\})$ [0.488, 0.639]	$m_{1-2}(\{\emptyset\})$ [0.096, 0.243]	$m_{1-2}(\{s_1\})$ [0.010, 0.031]
$m_2(\{s_2\})$ [0.341, 0.492]	$m_{1-2}(\{\emptyset\})$ [0.195, 0.386]	$m_{1-2}(\{s_2\})$ [0.067, 0.187]	$m_{1-2}(\{s_2\})$ [0.007, 0.024]
$m_2(\{s_1, s_2\})$ [0.016, 0.024]	$m_{1-2}(\{s_1\})$ [0.009, 0.019]	$m_{1-2}(\{s_2\})$ [0.003, 0.009]	$m_{1-2}(\{s_1, s_2\})$ [0.000, 0.001]

craft. The formula contains membership functions for terms respectively "likely" ($k = 3$), "fairly likely" ($k = 2$) and "very low" ($k = 0$). Functions are quads calculated with formula (1) for listed above k value. Membership functions are also presented as intervals for three selected possibility levels $\alpha = 0$, 0.5 and 1. Possibility equal to zero denotes support of a fuzzy value. Possibility equal to one refers to the core of imprecise value.

$$\begin{aligned}
m(\{r_1\}) &= (0.4, 0.44, 0.76, 0.8) \approx \begin{bmatrix} \alpha = 0 & [0.4, 0.8] \\ \alpha = 0.5 & [0.42, 0.78] \\ \alpha = 1 & [0.44, 0.76] \end{bmatrix} \\
m(\{r_2\}) &= (0.2, 0.24, 0.56, 0.6) \approx \begin{bmatrix} \alpha = 0 & [0.2, 0.6] \\ \alpha = 0.5 & [0.22, 0.58] \\ \alpha = 1 & [0.24, 0.56] \end{bmatrix} \\
m(\{r_1, r_2\}) &= (0, 0, 0.16, 0.2) \approx \begin{bmatrix} \alpha = 0 & [0, 0.2] \\ \alpha = 0.5 & [0, 0.18] \\ \alpha = 1 & [0, 0.16] \end{bmatrix}
\end{aligned} \tag{4}$$

3 COMBINATION OF TWO BELIEF STRUCTURES

Probability assignments that examples are showed above can be combined in order to increase result information context. Probability assignment to events from frame of discernment at hand is called as belief structure. Belief structures are supposed to verify certain constraints (see for example definition (1)). Depending on type of assigned masses basic, interval-valued and fuzzy-valued structures are distinguished. It is said that combination of belief structures creates new assignment characterized by enrichment of engaged data. To take benefit of this enrichment other sources of data are to be available. In the above interval-valued example on guessing which of routes r_1 or r_2 will be taken by the vessel single source of data was assumed. Let us consider yet another archive that contains different sets of recorded cases. Registered routes for similar ships referred to similar weather conditions were analyzed. Number of records in the samples varied within range of [40, 60]. Data analyses revealed that number of southwest bound ships that have chosen route r_1 never fell below 50% and did not exceed 65% of the total number. Masses attributed to each event are shown in formula (5).

$$\begin{aligned}
m_2(\{r_1\}) &= [m_{21}^-, m_{21}^+] = [0.488, 0.639] \\
m_2(\{r_2\}) &= [m_{22}^-, m_{22}^+] = [0.341, 0.492] \\
m_2(\{r_1, r_2\}) &= [m_{23}^-, m_{23}^+] = [0.016, 0.024]
\end{aligned} \tag{5}$$

Combination procedure for ranges and fuzzy values extends original Dempster-Shafer method initially proposed for crisp masses in basic belief structures. Comprehensive way of two sources combinations is summarized below. The scheme was further used for example combination of the two discussed sources results are shown in table 1.

Dempster-Shafer rules of combination:

1. Create table with rows that refer to events embraced in second source.
   Columns refer to the events of first source.
   Each event has mass of evidence (fuzzy or interval-valued) that is assigned to it
2. For each intersection of a row and a column product of masses involved is calculate and attributed to a common, for the two sets, event.
   In case of crisp events inconsistency occurs if the two sets have empty intersection. Therefore, for particular cell, the product of masses of evidence is assigned to an empty set
   In case of fuzzy events conjunctive operator is applied and search for minimum values on membership functions involved carried out
3. Calculate masses for each resulting set of events
4. Calculate belief functions (and if required plausibility) values

Definition (2):

There are two sets of interval-valued masses attributed to elements of the same frame of discernment, namely: $\mathbf{m}_1$, $\mathbf{m}_2$. Each of them embraces certain set of events referred to as: $\mathcal{F}\delta(\mathbf{m}_1)$ and $\mathcal{F}(\mathbf{m}_2)$. Their combination defines probability assignment as a set $\mathbf{m}$ such that for $m \in \mathbf{m}$ appropriate limits (Denoeux 1999) are given by formula (6).

$$\begin{aligned}
m^-(A) &= \min_{(m_1, m_2) \in (\mathbf{m}_1 \times \mathbf{m}_2)} \sum_{B \cap C = A} m_1(B) m_2(C) \\
m^+(A) &= \max_{(m_1, m_2) \in (\mathbf{m}_1 \times \mathbf{m}_2)} \sum_{B \cap C = A} m_1(B) m_2(C)
\end{aligned} \tag{6}$$

Table 2. Joint masses, belief function values and tighten bounds.

Event	Joint masses	Interval-valued beliefs	Tighten intervals
$\{s_1\}$	[0.298, 0.551]	[0.298, 0.551]	[0.313, 0.529]
$\{s_2\}$	[0.077, 0.220]	[0.077, 0.220]	[0.078, 0.219]
$\{s_1, s_2\}$	[0.0003, 0.0012]	[0.471, 0.709]	[0.0003, 0.0012]

Using formula (6) one can obtain limits of joint masses that are as follows:

- $m^-_{1-2}(\{s_1\}) = 0.279 + 0.009 + 0.01 = 0.298$
- $m^+_{1-2}(\{s_1\}) = 0.501 + 0.019 + 0.031 = 0.551$
- $m^-_{1-2}(\{s_2\}) = 0.067 + 0.003 + 0.007 = 0.077$
- $m^+_{1-2}(\{s_2\}) = 0.187 + 0.009 + 0.024 = 0.220$
- $m^-_{1-2}(\{s_1, s_2\}) = 0.0003$
- $m^+_{1-2}(\{s_1, s_2\}) = 0.0012$

Since in two cases there were empty intersections therefore inconsistency occurred. Limits of the empty set are as below:

- $m^-(\emptyset) = 0.096 + 0.195 = 0.291$
- $m^+(\emptyset) = 0.386 + 0.243 + 0.529$

Result belief structure with its interval-valued probability assignment enables determination of evidential functions. Lower and upper limits of belief function can be calculated with formula (7).

$$bel^-(A) = \max\Big(\sum_{B\subseteq A;B\neq\emptyset} m^-(B),\ 1 - \sum_{B\not\subset A;B\neq A} m^+(B) - m^+(\emptyset)\Big)$$
$$bel^+(A) = \min\Big(\sum_{B\subseteq A;B\neq\emptyset} m^+(B),\ 1 - \sum_{B\not\subset A;B\neq A} m^-(B) - m^-(\emptyset)\Big) \quad (7)$$

Taking into account limits of empty sets obtained during combination ranges of believes for each of the events are as shown in table 2.

MTE defines belief function in terms of the mass of evidence assigned to each event and its constituents, if available. Thus in order to obtain total belief committed to the set, masses of evidence associated with all the sets that are subsets of the given set must be added. Consequently beliefs of atomic event remain unchanged and equal to combined values. Joint events increase their belief values according to constituents masses (see last row in table 2).

3.1 *Evidence combination as optimization problem*

Presented procedure is an extension of initial Dempster proposal intended for structures with crisp events as well as crisp masses assigned to the events. Extension of the approach substitute crisp values with interval-valued probabilities. Subsequently principles of adequate mathematics are to be applied.

Unfortunately such direct modification can lead to results that are too broad. The new approach toward data association is to be considered since its results are to be tightened. Problem of combination of interval-valued structures can be introduced as following optimization task (Denoeux 1999).

Search for lower and upper limits of combined structure:

$$m^-_A(m_1, m_2) = \min \sum_{B\cap C=A} m_1(B) * m_2(C)$$
$$m^+_A(m_1, m_2) = \max \sum_{B\cap C=A} m_1(B) * m_2(C) \quad (8)$$

Under constraints:

$$\sum_{B\in\mathcal{F}(m_1)} m_1(B) = 1$$
$$\sum_{C\in\mathcal{F}(m_2)} m_1(C) = 1$$
$$m^-_1(B) \le m_1(B) \le m^+_1(B) \quad \forall B \in \mathcal{F}(m_1)$$
$$m^-_1(C) \le m_1(C) \le m^+_1(C) \quad \forall C \in \mathcal{F}(m_2) \quad (9)$$

Adequate optimization problem was solved using available software and results are shown in the rightmost part of table 2. It is seen that optimization leads to results falling within limits established with previous method. All further results of combination presented in the paper were obtained using software available at website:

http://www.hds.utc.fr/~tdenoeux/.

The software implements procedures solving above defined optimization problem.

4 BELIEF STRUCTURES IN MARITIME NAVIGATION

Previously presented case of guessing which route will be taken by unknown vessel, although interesting, is not very much representative for maritime navigation. Its typical problems are related to position fixing. The aim of the position interpretation is to find out what the distance from nearest obstacle could be. The distance given as crisp value is not of primary importance instead it subjective assessment really matters. Subjectivity should embrace local condition. Confined water distance of 4Nm must be differently perceived than the same distance in the open sea. Nevertheless safe or sufficient distance value is to be maintained everywhere and all the time. Example of the set of fuzzy-valued subjective distances is shown in figure 5.

Fixing can be directly transferred into appropriate state referring to the obstacle. Being within the

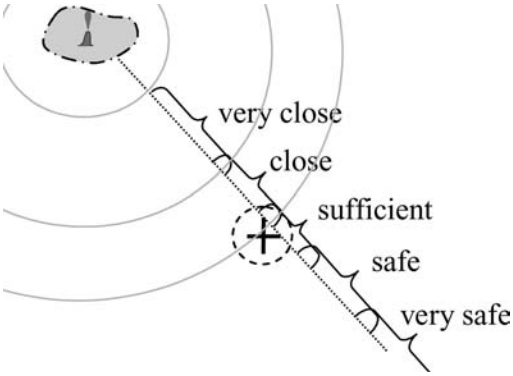

Figure 5. Distances from an obstacle expressed as fuzzy values.

Table 3. Meaning of 4 Nm off safe water buoy in the given area

	very close						sufficient					very safe				
	close									safe						
Expert	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1									+	+	+					
2								+	+	+	+					
3						+	+	+	+							
4								+	+	+						
5								+	+							
frequency						0.2	0.2	0.8	1.0	0.6	0.4					

state can be treated as an event in MTE terminology. From figure 5 it is also clear that limits of a state are imprecise values therefore event is not crisp any longer. In figure 5 circle around position cross reflects error, standard deviation attributed to particular system. Marked spot is somewhere in between "close" and "sufficient" distance if proposed limits are assumed. Instead of establishing borders one can ask experts what they think about, for example, 4 Nm off the buoy. They are to use scale that covers five terms from "very close" to "very safe". Table 3 contains results of the inquiry with 16 unity intervals scale. Each linguistic term covers four adjacent unity intervals. Extreme interval is assumed to be shared with neighbour term.

Last two rows of the table 3 embrace relative frequencies of answers for non-zero unity intervals. Set of these figures creates irregular membership function that will be written as:

$$\mu_{d1}(x_i) = \{0.2/6, 0.2/7, 0.8/8, 1/9, 0.6/10, 0.4/11\}$$

Unlike theoretical membership functions these similar to presented in table 3 are called empirical membership functions.

Accuracy of distance measured by a navigational aid depends on method and appliance involved. Different credibility is attributed to various aids. To conclude reasoning regarding measured distance one has to attribute mass of credibility to engaged system. Let us assume that example system's credibility is high. In this case using suggested 6-grade scale and formula 3 factor k will be assumed as equal to 4 (trapezoid regular membership function with $w_T = 0.8$ are further used). Doubtfulness regarding proper functionality of the aid and outcome of expert opinions is rather low ($k = 1$).

Above statements define following belief structure.

Measured distance to the obstacle expressed subjectively:

$$\mu_{d1}(x_i) = (0.2/6, 0.2/7, 0.8/8, 1/9, 0.6/10, 0.4/11)$$

Mass of credibility attributed to navigational aid and quality of expert opinions:

$$m_1(d_1) = (0.8, 0.84, 0.96, 1)$$

The last can be approximately expressed as:

$$m_1(d_1) \approx \begin{cases} \alpha = 1 & [0.84,\ 0.96] \\ \alpha = 0.5 & [0.82,\ 0.98] \\ \alpha = 0.0 & [0.80,\ 1] \end{cases}$$

Mass of uncertainty attributed to navigational aid and to quality of expert opinions:

$$m_1(\text{any}) = (0, 0.04, 0.36, 0.4)$$

This can be equivalent to:

$$m_1(\text{any}) \approx \begin{cases} \alpha = 1 & [0.04,\ 0.36] \\ \alpha = 0.5 & [0.02,\ 0.38] \\ \alpha = 0.0 & [0,\ 0.40] \end{cases}$$

The latest reflects statement that contradicts membership function shown in table 5. It expresses conclusion that engaged system might not work properly and indicates wrong data. Consequently every distance is equally possible. Membership function attached to such uncertainty consists of all one:

$$\mu_{any}(x_i) = (1/1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9, 1/10, 1/11, 1/12, 1/13, 1/14, 1/15, 1/16).$$

Assuming approximation of fuzzy values by interval values at selected possibility levels conditions of definition 1 are observed for all levels thus the above assignment is appropriate belief structure.

In order to enrich knowledge and reduce uncertainty regarding distance from the obstacle we assume that there is another navigational aid that indicates different distance and the aid is also reputed in different way. Another belief structure is as follows.

Measured distance to the obstacle expressed in subjective way:

$$\mu_{d2}(x_i) = (0.2/5, 0.4/6, 0.6/7, 1/8, 0.6/9, 0.2/10)$$

Table 4. Combination of two navigational aids.

	$m_1(\mu_{d1})$ $\alpha=1$ [0.84, 0.96] $\alpha=0.5$ [0.82, 0.98] $\alpha=0.0$ [0.80, 1]	$m_1(\text{any})$ [0.04, 0.36] [0.02, 0.38] [0, 0.40]
$m_2(\mu_{d2})$	$m_{1-2}(\mu_{d1} \wedge \mu_{d2})$ $\alpha=1$ [0.44, 0.76] [0.37, 0.73] $\alpha=0.5$ [0.42, 0.78] [0.34, 0.76] $\alpha=0.0$ [0.40, 0.80] [0.32, 0.80]	$m_{1-2}(\mu_{d2})$ [0.018, 0.27] [0.008 0.30] [0.0, 0.32]
$m_2(\text{any})$	$m_{1-2}(\mu_{d1})$ $\alpha=1$ [0.24, 0.56] [0.20, 0.54] $\alpha=0.5$ [0.22, 0.58] [0.18, 0.57] $\alpha=0.0$ [0.20, 0.60] [0.16, 0.60]	$m_{1-2}(\text{any})$ [0.01, 0.20] [0.004 0.22] [0.0 0.24]

Mass of credibility attributed to another navigational aid and quality of new expert opinions assumed as trapezoid fuzzy value ($k=3$ and $w_T=0.8$):

$$m_2(d_2) = (0.4, 0.44, 0.76, 0.8)$$

$$m_2(d_2) \approx \begin{cases} \alpha=1 & [0.44,\ 0.76] \\ \alpha=0.5 & [0.42,\ 0.78] \\ \alpha=0.0 & [0.40,\ 0.80] \end{cases}$$

Mass of uncertainty attributed to this positioning system and quality of other expert opinions expressed as trapezoid fuzzy value with $k=3$ and $w_T=0.8$):

$$m_2(\text{any}) = (0.2, 0.24, 0.56, 0.6)$$

$$m_2(\text{any}) \approx \begin{cases} \alpha=1 & [0.24,\ 0.56] \\ \alpha=0.5 & [0.22,\ 0.58] \\ \alpha=0.0 & [0.20,\ 0.60] \end{cases}$$

Same as before fuzzy values were approximated by interval values at three selected possibility levels. Conditions of definition 1 are observed for each of the levels thus the second assignment is also correct belief structure.

Indications coming from two sources were associated using extended Dempster-Shafer scheme and optimization approach. Obtained results are shown in table 4.

In table 4 there is expression $m_{1-2}(\mu_{d1} \wedge \mu_{d2})$ that remains to be explained. It is at the intersection of $m_2(\mu_{d2})$ row and $m_1(\mu_{d1})$ column and mean joint confidence regarding distances to the same obstacle measured by different navigational aid. In case of crisp events the mass would be assigned to empty set (∅). In case when events are fuzzy the expression should be written as $m_{1-2}(\mu_{d1}(x_i) \wedge \mu_{d2}(x_i))$ and interpreted as a mass of confidence attributed to conjunction of two fuzzy values respectively $\mu_{d1}(x_i)$ and $\mu_{d2}(x_i)$. In this case $\mu_{d1}(x_i) \wedge \mu_{d2}(x_i)$ =(0/5, 0.2/6, 0.2/7, 0.8/8, 1/9, 0.6/10, 0.4/11)∧(0.2/5, 0.4/6, 0.6/7, 1/8, 0.6/9, 0.2/10, 0/11) = (0/5, 0.2/6, 0.2/7, 0.8/8, 0.6/9, 0.2/10, 0/11). Note that conjunction ∧ means minimum operation in the two sets. As a result of combination of fuzzy events

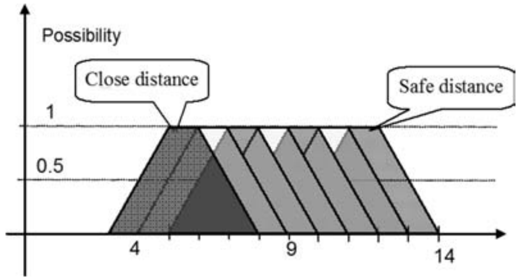

Figure 6. Bundle of benchmark membership functions.

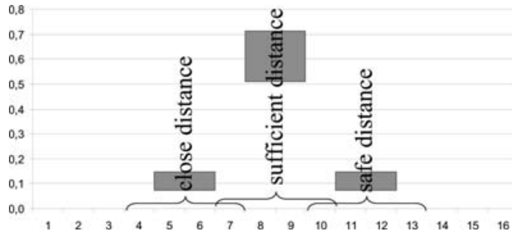

Figure 7. Belief intervals for close, sufficient and safe distances.

apart from initial sets appear yet another membership functions. The more sources are combined the more numerous count of such extra events. Note that such events bring some support for certain classes of fuzzy events.

Seemingly this phenomenon makes the approach vague. To some extent the statement is true. At the other hand result of combination could be treated as an encoded knowledge base. Having such database one is supposed to ask questions and get answers. As a matter of fact this is main advantage of the approach.

Kind of questions that can be submitted to the knowledge base depend on the problem at hand. In discussed case it could be interesting to know support for a statement that the distance from the obstacle is safe or sufficient one. Table 5 contains interval values of belief functions for different regular fuzzy functions related to considered scale of distances.

Benchmark membership functions used in table 5 are regular trapezoid ones presented in figure 6. They are based on sixteen unity interval scale as presented in table 3. First of the functions reflects term "safe", second one is shifted left (closer to the obstacle) by 1 unit and so on. In this way fourth function is related to sufficient distance and seventh to close condition.

Fuzzy belief functions values are given as α-cuts for $\alpha=1$, 0.5 and 0 in top to bottom order.

Figure 7 shows diagrams of three belief values marked with asterisk in table 5. They represent interval-valued beliefs that the distance is close, sufficient and safe, for the highest possibility level. The highest credibility with upper limit approaching 0.74 receives sufficient distance.

Table 5. Fuzzy beliefs for obtained combination results and selected fuzzy distances.

Pattern fuzzy value	Belief function	
	$\alpha = 1$	[0.074, 0.146]*
1 (0.5/10, 1/11, 1/12, 0.5/13) safe	$\alpha = 0.5$	[0.069, 0.153]
	$\alpha = 0.0$	[0.064, 0.160]
	$\alpha = 1$	[0.114, 0.195]
2 (0.5/9, 1/10, 1/11, 0.5/12)	$\alpha = 0.5$	[0.105, 0.197]
	$\alpha = 0.0$	[0.096, 0.200]
	$\alpha = 1$	[0.376, 0.493]
3 (0.5/8, 1/9, 1/10, 0.5/11)	$\alpha = 0.5$	[0.364, 0.497]
	$\alpha = 0.0$	[0.352, 0.500]
	$\alpha = 1$	[0.510, 0.714]*
4 (0.5/7, 1/8, 1/9, 0.5/10) sufficient	$\alpha = 0.5$	[0.493, 0.727]
	$\alpha = 0.0$	[0.476, 0.740]
	$\alpha = 1$	[0.358, 0.475]
5 (0.5/6, 1/7, 1/8, 0.5/9)	$\alpha = 0.5$	[0.347, 0.480]
	$\alpha = 0.0$	[0.336, 0.484]
	$\alpha = 1$	[0.155, 0.315]
6 (0.5/5, 1/6, 1/7, 0.5/8)	$\alpha = 0.5$	[0.141, 0.326]
	$\alpha = 0.0$	[0.128, 0.336]
	$\alpha = 1$	[0.074, 0.146]*
7 (0.5/4, 1/5, 1/6, 0.5/7) close	$\alpha = 0.5$	[0.069, 0.153]
	$\alpha = 0.0$	[0.064, 0.160]

5 CONCLUSIONS

Bridge officer has to use different navigational aids in order to refine position of the vessel. To combine various sources he uses his common sense or relies on traditional way of data association. So far Kalman filter proved to be most famous method of data integration. Mathematical Theory of Evidence delivers new ability. It can be used for data combination that results in their enrichment. Dempster-Shafer scheme initially designed for crisp data association now is widely used to cope with imprecision, which is expressed by intervals or fuzzy values. Assignment of masses of evidence to each of events at hand creates belief structure. Crisp, interval-valued and fuzzy-valued belief structures are distinguished.

In the paper interval-valued belief structure is defined. It is also shown that transition from interval to fuzzy-valued structure is straightforward. Example of such structures for position fixing was presented. The structures were then combined and results discussed. The most important conclusion that can be drawn from included example is that with help of MTE quantification of imprecise statement is possible. With at least two navigational aids engaged credibility that the distance from an obstacle is safe receives its unique, although interval or fuzzy-valued belief.

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12.5 The H_2 and robust H_{inf} regulators applied to multivariable ship steering

W. Gierusz
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The main goal of this task was a calculation of the two multivariable regulators for precise steering of a real, floating, training ship. The first one minimized the H_2 norm of the closed-loop system. The second one was related to the H_{inf} norm. The robust control approach was applied in this controller with the usage of the structured singular value concept. Both controllers are described in the first part of the paper. Details of the training vessel and its simulation model then are presented. The state model of the control object obtained via identification process is described in the next section. This model with matrices weighting functions was the base for creation of 'the augmented state model' for the open-loop system. The calculation results of the multivariable controllers is also shown in this section. Several simulations were performed in order to verify the control quality of both regulators. Exemplary results are presented at the end of this paper together with final remarks.

1 INTRODUCTION

The process of the ship movement steering can be divided into several control subsystems, e.g. the ship's course and/or speed stabilization, damping of roll angle, dynamic ship positioning (DSP), guidance along trajectory etc. One of them is the control system for precise steering of the ship moving with the low and very low speed. Such kind of the vessel motion is also known as a crab movement. This regulation process means the full control of velocities during translation of the ship with any drift angle, e.g. motion ahead, astern and askew or rotation in place. No other help (tugs, anchors etc.) is required for this process.

In the beginning, the precise steering systems were installed as extensions of DSP units on research ships, drilling vessels, cable and pipe laying ships and similar ones. Nowadays these systems are mounted on ferries, passenger ships, shuttle tankers, FSO and dredging vessels (Fossen 2002).

The exemplary manoeuvres under such a steering are presented in Fig. 1. It gives, among others, the following advantages:

- the increasing safety of the vessel, especially on constrained water with intensive traffic (harbours, navigation channels, closed or inner roads etc.), owing to ability to perform e.g. a fast anticollision manoeuvre on very small area,
- the possibility of resignation of tugs cooperation for e.g. berthing or mooring manoeuvres,
- the ability to pass along very shallow and tortuous navigation channels, inaccessible for ships with conventional drivers e.g. near attractive touristic places (islands, gulfs, fiords, etc.).

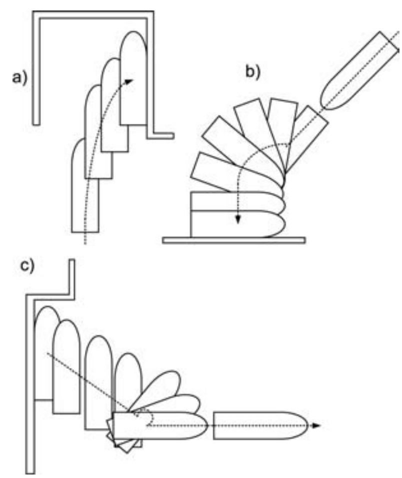

Figure 1. The exemplary situations when precise manoeuvres during berthing are needed and expected.

For this purpose the ship has to be equipped with at least a few driving devices like: main propellers, tunnel thrusters, jet-pump thrusters, or azipods (a blade rudder is useless in such operations). They allow to steer the ship in the manual manner, but it rarely leads to satisfying results – therefore the multivariable controller seems to be a reasonable solution.

The regulation of three ship's velocities: surge, sway and yaw often needs the 'usage' of only one velocity at a time (see Fig. 1), therefore the control system should ensure complete or almost complete de-coupling steering of the ship.

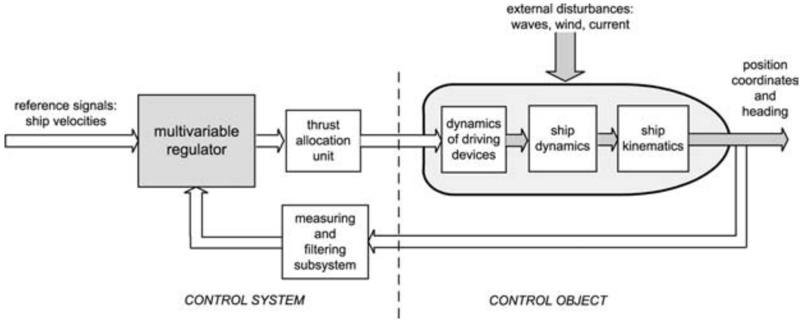

Figure 2. The block diagram of the multivariable ship control system.

The whole described system (see Fig. 2) consists of three elements:

– the measuring subsystem,
– the multivariable regulator,
– the thrust allocation unit.

As it was pointed out the precise steering of the vessel is performed with very slow velocities. The standard navigation devices for measuring of motion parameters have poor accuracy in these work conditions. Therefore ship's velocities have to be estimated (reconstructed) from position coordinates and a value of the heading. The Kalman filters are commonly used for this purpose (Anderson & Moore 2005).

The ship as a control object has very disadvantageous features:

- the characteristics of the ship strongly and in the nonlinear manner depend on operating conditions e.g. the ship's velocity, the direction of the motion, ship load, water depth, proximity of other ships, wharfs, etc.
- the allowance for all these factors in the model is very difficult and even after it has been done it leads to a badly complicated structure useless for synthesis,
- the linearization of the model in many working points gives a family of the models and the family of regulators. Next it generates another problem with the process of proper controllers shockingless switching.

A control system designer has two main ways to overcome these problems. One of them is matching regulator to the real plant during the control process i.e. adaptation of the control system – see for example Astrom and Wittenmark books or (Niederlinski, Moscinski & Ogonowski 1995). The second way is evaluation of the bounds of the plant (ship) changes and including them into the regulator synthesis process (Skogestad & Postlethwaite 2003), (Zhou 1998). The last approach is often named H_{inf} robust control and requires a minimization of a process matrix norm called H_{inf} (Doyle, Glover, Khargonekar & Francis 1989).

The matrix norms are very convenient ways for formulation of performance criterions, especially in multivariable systems. One can use two norms: H_{inf} and H_2. Controllers related to each norm are commonly named 'H_{inf} regulator' and 'H_2 regulator'. The synthesis of both controllers for a ship is the objective of this paper.

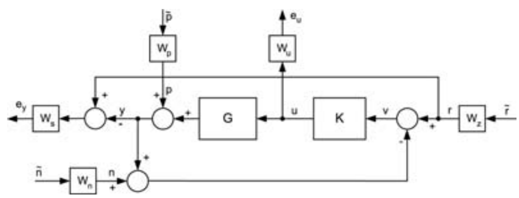

Figure 3. The block diagram of the closed-loop system with weighting functions for selected signals. The meaning of the particular signals is as follows: $\tilde{r}$ = references vector, $\tilde{p}$ – vector of disturbances, $\tilde{n}$ – noises vector, $\tilde{e}_y$ – weighted control errors, $\tilde{e}_u$ – weighted control signals.

2 THE H_{inf} AND H_2 REGULATORS

2.1 Problem formulation

The feedback controller design can be formulated for the general configuration of the MIMO system shown in Fig. 3 (note opposite directions of signals – from right to left hand side, more convenient for matrix operations used in multivariable systems).

The concept of weighting functions is a convenient way of introducing different signal specifications into a MIMO process:

- the signals scaling operation is easy to perform by means of this functions,
- one can distinguish between more and less important components of the signals vectors (e.g. in errors vector) by proper gain coefficients, introduced into these functions,
- the designer requirements related to the particular signals can be formulated for specified frequency ranges in a natural way.

Note the different sense of functions $\mathbf{W_u}$, $\mathbf{W_s}$ on the one hand and $\mathbf{W_p}$, $\mathbf{W_n}$, $\mathbf{W_z}$ on the other one. Functions matrices $\mathbf{W_s}$ and $\mathbf{W_u}$ define designer requirements for

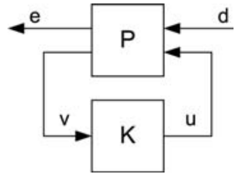

Figure 4. The generalized closed-loop system configuration.

steering quality in the system while functions matrices $\mathbf{W_p}$, $\mathbf{W_n}$ and $\mathbf{W_z}$ form input signals in frequency domain. One can write the following equations based on the Fig. 3:

$$\mathbf{e_y} = \mathbf{W_s W_z \tilde{r}} - \mathbf{W_s W_p \tilde{p}} - \mathbf{W_s G u} \tag{1}$$

$$\mathbf{e_u} = \mathbf{W_u u} \tag{2}$$

$$\mathbf{v} = \mathbf{W_z \tilde{r}} - \mathbf{W_p \tilde{p}} - \mathbf{W_n \tilde{n}} - \mathbf{W_s G u} \tag{3}$$

$$\mathbf{u} = \mathbf{K v} \tag{4}$$

Above equations can be rewritten in more compact form:

$$\begin{bmatrix} \mathbf{e_y} \\ \mathbf{e_u} \\ \mathbf{v} \end{bmatrix} = \mathbf{P} * \begin{bmatrix} \mathbf{\tilde{r}} \\ \mathbf{\tilde{p}} \\ \mathbf{\tilde{n}} \\ \mathbf{u} \end{bmatrix} \tag{5}$$

where matrix $\mathbf{P}$ has the form:

$$\mathbf{P} = \begin{bmatrix} \mathbf{W_s W_z} & -\mathbf{W_s W_p} & \mathbf{0} & -\mathbf{W_s G} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{W_u} \\ \mathbf{W_z} & -\mathbf{W_p} & -\mathbf{W_n} & -\mathbf{G} \end{bmatrix} \tag{6}$$

Matrix $\mathbf{P}$ is called the augmented plant (model plant) due to weighting functions vectors included in it. Introducing the input vector $\mathbf{d} = [\mathbf{\tilde{r}}\ \mathbf{\tilde{p}}\ \mathbf{\tilde{n}}]^T$ and the weighting error vector $\mathbf{e} = [\mathbf{e_y e_u}]^T$ one can write:

$$\begin{bmatrix} \mathbf{e} \\ \mathbf{v} \end{bmatrix} = \mathbf{P} * \begin{bmatrix} \mathbf{d} \\ \mathbf{u} \end{bmatrix} \tag{7}$$

$$\mathbf{u} = \mathbf{K} * \mathbf{v} \tag{8}$$

The last equations enable to build the generalized configuration exposed in Fig. 4.

Now the weighting error vector can be expressed in the form:

$$\mathbf{e} = \mathbf{T_{ed}}(\mathbf{P}, \mathbf{K}) * \mathbf{d} \tag{9}$$

where matrix $\mathbf{T_{ed}}$ can be obtained by means of the Lower Linear Fractional Transformation (Redheffer 1960).

The control system design can be treated as a process of calculating a controller $\mathbf{K}$ such which maintain small certain weighted signals (e.g. control errors). One of the possible way to define the 'smallness' of signals (or transfer matrices) are matrix norms H_{inf} and H_2 (Skogestad & Postlethwaite 2003) expressed by the following equations:

$$\|\mathbf{T_{ed}}(\mathbf{s})\|_2 = \sqrt{\frac{1}{2\pi} \int_{-\infty}^{+\infty} tr[\mathbf{T_{ed}}(\mathbf{j}\omega)^* \mathbf{T_{ed}}(\mathbf{j}\omega)] d\omega}$$

$$\|\mathbf{T_{ed}}(\mathbf{s})\|_\infty = \max_{\omega \in \langle 0, \infty \rangle} \overline{\sigma}[\mathbf{T_{ed}}(\mathbf{j}\omega)] \tag{10}$$

2.2 *The H_2 regulator*

The H_2 optimal control problem is to find a controller $\mathbf{K}$ which stabilizes the closed-loop system (presented in Fig. 4) and minimizes the H_2 norm of this system. The minimization of the H_2 norm is performable only for strictly proper systems. When the plant $\mathbf{P}$ is written in state model form:

$$\begin{bmatrix} \dot{x} \\ e \\ v \end{bmatrix} = \left[\begin{array}{c|cc} A & B_1 & B_2 \\ \hline C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{array} \right] * \begin{bmatrix} x \\ d \\ u \end{bmatrix} \tag{11}$$

the part D_{11} and D_{22} must be a matrices of zeros for such a system.

The well-known LQG controller can be treated as a special case of the H_2 regulator, when a weighting factor in LQG performance criterion is included into weighting function $\mathbf{W_u}$ (Zhou 1998).

The regulator which minimizes the H_2 norm of the system ensures the proper steering quality represented by the matrix weighting functions $\mathbf{W_s}$ and/or $\mathbf{W_u}$ (see Fig. 3), but under assumption that the plant model is adequate and accurate.

2.3 *The H_{inf} regulator*

The goal of H_{inf} regulator is similar to that of the H_2 one, but now one wants to minimize the H_{inf} norm with the condition:

$$\|\mathbf{T_{ed}}(\mathbf{P}, \mathbf{K})\|_\infty < \gamma, \qquad \gamma > 0, \qquad \gamma \in \Re \tag{12}$$

The value γ has the sense of the energy ratio between error vector $\mathbf{e}$ and exogenous input vector $\mathbf{d}$. When the γ tends to its minimal value the above formulation is often named the optimal H_∞ control problem (Skogestad & Postlethwaite 2003).

The regulator which minimizes the H_{inf} norm of the system ensures similar quality of the steering **for any combinations of exogenous input signals** formed by matrix weighting functions $\mathbf{W_p}$, $\mathbf{W_n}$ and $\mathbf{W_z}$ (note that this is not warranted by H_2 regulator).

2.4 *The robust regulator*

However this steering quality is only achieved under the same assumption that the plant model is accurate. If the real plant differs (e.g. due to operating conditions) from the model used during controller synthesis

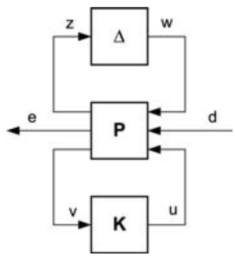

Figure 5. The generalized closed-loop system configuration with uncertainties.

this quality can be significantly poor. The differences between the object and the model are usually named the system uncertainties (Doyle 1982).

There are several sources of uncertainties which can be introduced into the ship model:

– changes the physical parameters of the vessel due to different work conditions (e.g. load, trim, depth of water, etc.),
– errors in estimation process for model coefficients values,
– neglected nonlinearities inside the object (e.g. related to hydrodynamics phenomena),
– measurement and filtration process errors (e.g. biases),
– unmodelled dynamics, especially in the high frequency range,
– accepted (chosen) limitation of the model order.

All uncertainties can be divided into two classes: parametric ones, related to the particular model coefficients and others – nonparametric ones. Introduction of the concept of uncertainties into the modelling process means that one considers not only the one nominal model of the object $\mathbf{G_n}(\mathbf{j}\omega)$, but a family of models $\mathbf{G_D}$ spread around this nominal model.

The uncertainties can be introduced into the system model in different ways, depending on their types and locations, but all of them are represented by means of two components:

– the first one is the "pure" uncertainty Δ, bounded in the H_{inf} norm sense i.e. $\|\Delta\|_\infty \leq 1$
– the second one it is the weighting function modeling the magnitude and shape of the uncertainty in the frequency domain.

Consequently, any closed-loop system with uncertainties contains three basic components: the generalized (augmented) plant **P**, the controller **K** that has to be obtained and the set of "pure" uncertainties Δ, collected in the matrix form (see Fig. 5).

The augmented plant **P** consists of the nominal object model $\mathbf{G_n}$ and of all matrices of weighting functions (modeling the performance requirements, forming input signals and describing the uncertainties). Note that the augmented plant **P** for H_{inf} controller synthesis slightly different from this plant for H_2 one.

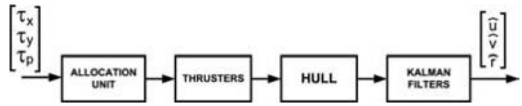

Figure 6. The block diagram of control object.

2.5 *The ship subsystems as a control object*

The control object denoted $\mathbf{G_n}$ (see Fig. 3) in the considered system consists of four elements: the allocation unit, thrusters set, the ship and the filters system (Gierusz 2006). It has three inputs: two demanded forces τ_x and τ_y for longitudinal and lateral directions of movement and one moment τ_p for turning (in the ship-fixed frame) and three outputs: estimated values of velocities surge $\hat{u}$, sway $\hat{v}$ and yaw $\hat{r}$ (see Fig. 6).

3 CASE STUDY

3.1 *The training ship*

The H_2 and H_{inf} robust controllers was applied to steer a floating training ship. The vessel named 'Blue Lady' is used by the Foundation for Safety of Navigation and Environment Protection at the Silm lake near Ilawa in Poland for training of navigators. It is one of the series of 7 various training ships exploited on the lake.

The ship 'Blue Lady' is an isomorphous model of a VLCC tanker, built of the epoxide resin laminate in 1:24 scale. It is equipped with battery-fed electric drives and the two persons control steering post at the stern. The silhouette of the ship is presented in Fig. 7.

The main parameters of the ship are as follows:

Length over all $L_{OA} = 13.78[m]$
Beam $B = 2.38[m]$
Draft (average) – load condition $T_l = 0.86[m]$
Displacement – load condition $\Delta_l = 22.83[t]$
Speed $V = 3.10[kn]$

The high-fidelity, fully coupled, nonlinear simulation model of this ship was built for controllers synthesis. Special attention was paid to the proper modeling of the ship's behaviour during movement with any drift angle (e.g. astern or askew). The block diagram of the model is presented in Fig. 8 (see (Gierusz 2001) for detailed description of this model).

3.2 *The linear model identification*

The synthesis processes of both controllers described in this paper need a linear model of the object. There are two ways to create it: a linearization of a nonlinear (e.g. simulation) model of the vessel dynamics or identification way. The second approach was used in presented work.

Every identification experiment was performed as a simulation run in Simulink environment. More than one hundred of experiments were performed for this purpose (Gierusz 2006).

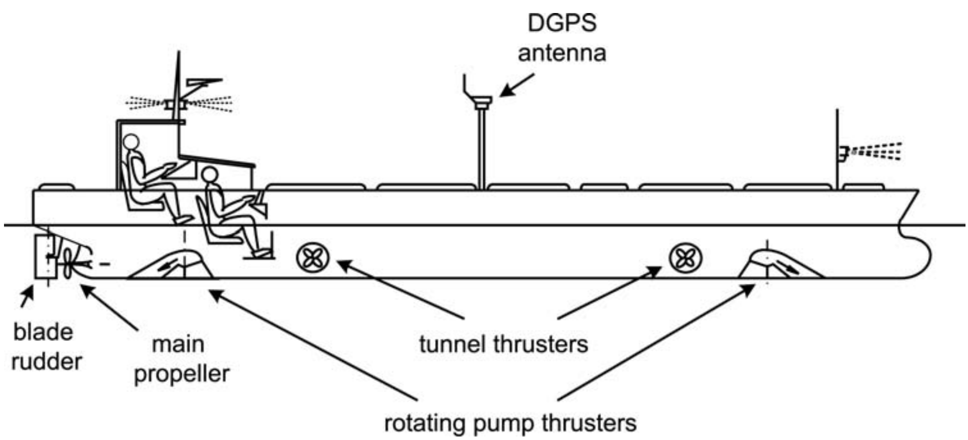

Figure 7. The outline of the training ship "Blue Lady" .

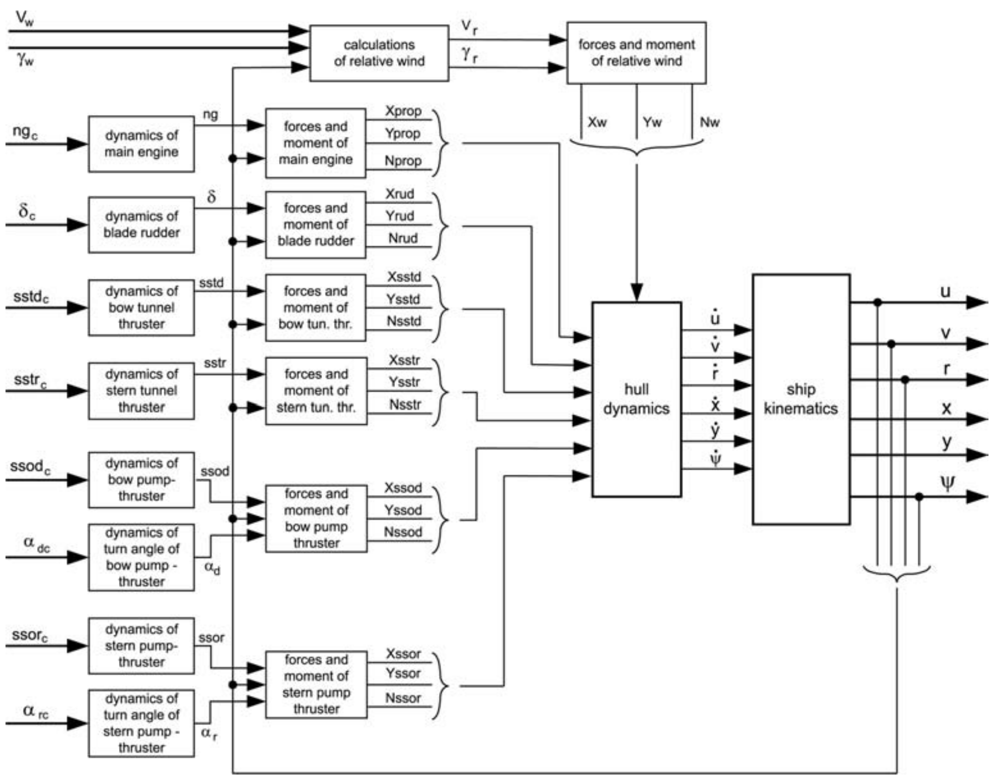

Figure 8. The block diagram of the *'Blue Lady'* simulation model. Input signals for the model are as follows (from top to bottom): mean wind velocity – V_w, mean wind direction – γ_w, revolutions of the main propeller – ng_c, blade rudder angle – δ_c, relative thrust of the bow (stern) tunnel thruster – $sstd_c$ ($sstr_c$), relative thrust of the bow pump thruster – $ssod_c$, turn angle of the bow pump thruster – α_{dc}, relative thrust of the stern pump thruster – $ssor_c$, turn angle of the stern pump thruster – α_{rc}. The output signals of the model are: surge – u, sway – v, yaw – r, position coordinates – x,y and the heading – Ψ.

During identification process, it turned out, that three subsystems demonstrated weak correlation between output and input signals ($\tau_x \to v, \tau_y \to u$, $\tau_p \to u$), therefore these subsystems were canceled from the whole model (see Fig. 9).

Finally, the third order state model was obtained. The average values of coefficients, obtained in all identification experiments were chosen as the values of parameters of the nominal model $\mathbf{G_n}$. Note values of coefficients equal 0 in the

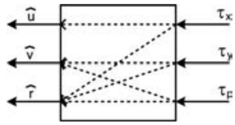

Figure 9. Control object paths to be identified.

channels cancelled during identification process (see Fig. 9).

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix} = \begin{bmatrix}a_{uu} & 0 & 0\\ 0 & a_{vv} & a_{vr}\\ a_{ru} & a_{rv} & a_{rr}\end{bmatrix} * \begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} + \begin{bmatrix}b_{uu} & 0 & 0\\ 0 & b_{vv} & b_{vr}\\ b_{ru} & b_{rv} & b_{rr}\end{bmatrix} * \begin{bmatrix}\tau_x\\ \tau_y\\ \tau_p\end{bmatrix} \quad (13)$$

$$\begin{bmatrix}u\\ v\\ r\end{bmatrix} = \begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix} * \begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} \quad (14)$$

The resultant model is state controllable and observable – see (Gierusz & Tomera 2006) for details.

This model was used for $\mathbf{H_2}$ controller synthesis.

For synthesis of the robust regulator five parametric uncertainties (denoted $\delta_i, \quad i = 1, \ldots, 5$) were introduced into the state model due to the wide range of variations of parameter values acquired in various experiments. This model had the form:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix} = \begin{bmatrix}a_{uu}+\delta_{11} & 0 & 0\\ 0 & a_{vv}+\delta_{12} & a_{vr}\\ a_{ru} & a_{rv} & a_{rr}+\delta_{13}\end{bmatrix} * \begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} + \begin{bmatrix}b_{uu}+\delta_{14} & 0 & 0\\ 0 & b_{vv} & b_{vr}+\delta_{15}\\ b_{ru} & b_{rv} & b_{rr}\end{bmatrix} * \begin{bmatrix}\tau_x\\ \tau_y\\ \tau_p\end{bmatrix} \quad (15)$$

$$\begin{bmatrix}u\\ v\\ r\end{bmatrix} = \begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix} * \begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} \quad (16)$$

The coefficients values of the state model of the ship dynamics with values of uncertainties are collected in the table 1 below.

Table 1. The values of model coefficients.

Wsp.	Nominal value	Real uncertainty value	Relative uncertainty value [%]
a_{uu}	$-3.36 * 10^{-3}$	$2.64 * 10^{-3}$	78
a_{vv}	$-9.00 * 10^{-3}$	$5.00 * 10^{-3}$	64
a_{vr}	$-2.00 * 10^{-4}$	–	–
a_{ru}	$-3.00 * 10^{-3}$	–	–
a_{rv}	$-1.00 * 10^{-3}$	–	–
a_{rr}	$-7.75 * 10^{-3}$	$4.05 * 10^{-3}$	52
b_{uu}	$+3.62 * 10^{-3}$	$1.51 * 10^{-3}$	42
b_{vv}	$+2.06 * 10^{-3}$	–	–
b_{vr}	$+1.61 * 10^{-5}$	$2.89 * 10^{-5}$	179
b_{ru}	$+3.00 * 10^{-5}$	–	–
b_{rv}	$+1.15 * 10^{-5}$	–	–
b_{rr}	$+8.00 * 10^{-3}$	–	–

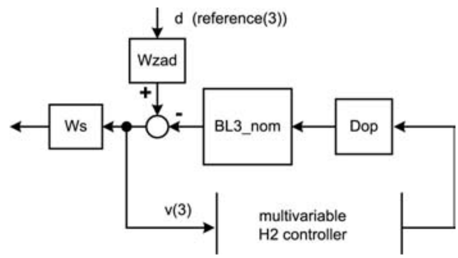

Figure 10. The block diagram of the augmented open-loop process for H_2 controller synthesis. Symbols denote: **BL3_nom** – state model of the control object; **Dop** – adaptation matrix; **Wzad** – filters for reference signals; **Ws** – weighting functions for control performance. Numbers in parentheses denote sizes of the signal vectors.

3.3 *The controllers synthesis*

3.3.1 *H_2 regulator*

The state model, presented via equations (13) and (14), could be arranged into 'augmented state model of the open-loop process' (Balas, Doyle, Glover, Packard & Smith 2001), which was necessary to compute the multivariable controller which minimized H_2 norm.

The three tracking velocity errors e_u, e_v and e_r were chosen as a performance criterion. It was assumed that these expected errors would depend on frequency of the reference signals. These requirements were transferred into the matrix of the weighting functions **Ws** for each velocity. The matrix of the weighting function **Wzad** was introduced instead, to moderate the reference signals rate and consequently to constrain the possibly large amplitude of the steering signals.

The block diagram of model for this process is presented in Fig. 10.

The synthesis of the regulator was made by means of the algorithm named 'h2syn' from 'μ Analysis and Synthesis Toolbox'(see (Balas et al. 2001) for more details).

The computed regulator is of order 15:

$$\dot{\mathbf{x}}(\mathbf{t}) = \mathbf{A}_r^{15x15} * \mathbf{x}(\mathbf{t}) + \mathbf{B}_r^{15x3} * \mathbf{v}(\mathbf{t}) \quad (17a)$$

$$\tau_c = \mathbf{C}_r^{3x15} * \mathbf{x}(\mathbf{t}) + \mathbf{D}_r^{3x3} * \mathbf{v}(\mathbf{t}) \quad (17b)$$

The value of the closed-loop system H_2 norm was 12.14 and the value of the H_∞ norm was between 23.9365 and 23.9604. This last value means that the H_2 controller is not a robust one for the described system.

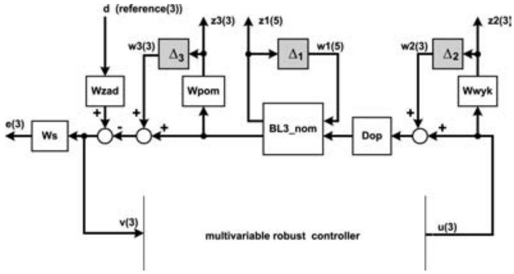

Figure 11. The block diagram of the augmented open-loop process. Symbols denote: Δ_1 – structured uncertainties block; Δ_2 – input uncertainty with weighting functions **Wwyk**; Δ_3 – measuring and filtering uncertainty with weighting functions **Wpom**; **BL3_nom** – state model of the control object; **Dop** – adaptation matrix; **Wzad** – filters for reference signals; **Ws** – weighting functions for robust performance. Numbers in parentheses denote sizes of the signal vectors.

3.3.2 H_{inf} regulator

Apart from uncertainties related to changing properties of the plant, (see equations (15) and (16)) two multiplicative, nonparametric uncertainties were introduced to the presented ship control system. The first one modelled inaccuracy in input signals (related to transmission errors) with the matrix of weighting function **Wwyk**, and the second one modelled measuring and filtering errors in the output plant with the matrix of weighting function **Wpom**. The state model of the control object with all weighting functions was rebuilt into 'augmented state model of the open-loop process' much more complicated then one presented in Fig. 10:

The algorithm named 'D-K iteration' from mentioned Matlab toolbox was used to compute the robust H_{inf} controller for the system presented in Fig. 11. The obtained regulator in state model form was of high order equal to 41 – the same as the open-loop system (with the scaling matrices **D** – see (Balas et al. 2001) for the meaning of such matrices).

The value of H_{inf} norm was $0.56 < 1$ which ensures the robust property of the controller.

Therefore the order reduction procedures were performed. Finally the controller of the order 21 was obtained.

The regulator order seems to be quite high, but it is worth to remember what the introduction of parametric uncertainties to the plant model is. It means that the obtained controller should steer properly (in weighing functions sense) the object which can change its characteristic in a very wide range. Therefore, the controller for such object should not be so simple.

4 RESULTS ANALYSIS AND FINAL REMARKS

The examination of both control systems was performed during simulation runs with the ship's nonlinear simulation model.

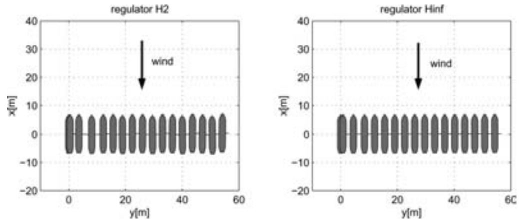

Figure 12. The trajectory of the ship in the first example drawn by silhouettes every 60[s]. Initial heading $\psi_0 = 0[deg]$, the trial period $t = 1000[s]$. An arrow indicate the average wind direction

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Every Figure is divided into two parts. The left-hand side presents the results of the steering with the H_2 controller and the right-hand side presents the same trials performed with the robust regulator.

This example is illustrated by means of 3 Figures:

- the trajectory, drawn by ship's silhouettes every 60[s],
- ship's velocities (reference signals and real values), supplemented by wind velocity runs (presented in Beaufort scale)
- command signals from the regulators.

The results were recalculated to start both trajectories from point (0,0) and the initial heading was chosen as 0 [deg].

One can compare the tracking errors for all velocities in all presented examples . The following formula was used for this purpose:

$$J_q = \frac{1}{T}\sum_{i=1}^{T}(q_c(i) - \hat{q}(i))^2, \quad q = \{u, v, r\} \quad (18)$$

where: q_c – reference signal for particular velocity,
$\hat{q}$ – estimated value from Kalman filter,
T = 1000, 1400, 2800 successively for first, second and third example.

The comparisons are presented in the tables (values $\times 10^6$):

Example 1

Controller	J_u	J_v	J_r
H_2	35	127	191
H_{inf}	1	73	29

Example 2

Controller	J_u	J_v	J_r
H_2	369	3	660
H_{inf}	37	1	230

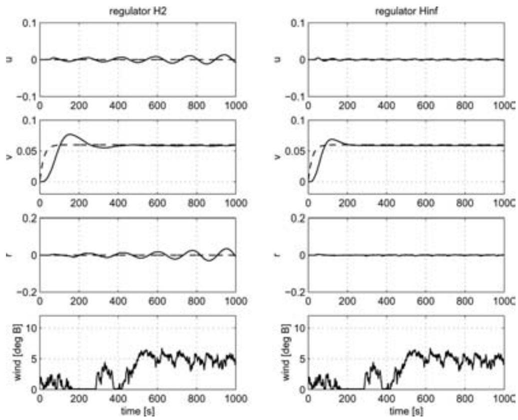

Figure 13. The velocities of the ship in the first example – from the top: surge, sway and yaw. The bottom figures present the wind speed in Beaufort scale (recalculated in the ship model scale 1:24). Solid lines denote real values, dashed lines – commands.

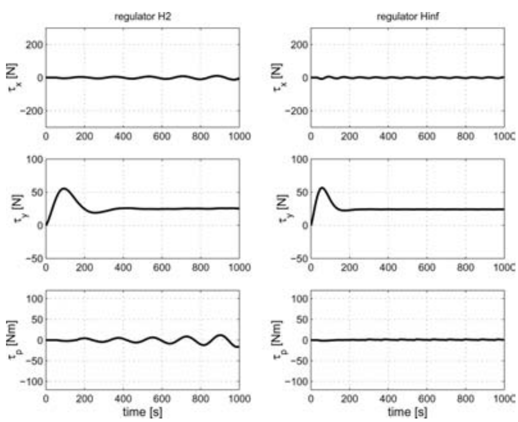

Figure 14. The commands from controllers – from the top: for surge – τ_x, for sway – τ_y and for yaw – τ_p.

Example 3

Controller	J_u	J_v	J_r
H_2	2650	205	3280
H_{inf}	920	109	2270

The similar calculations one can perform for control effort for both regulators using the formula:

$$J_{\tau s} = \frac{1}{T}\sum_{i=1}^{T}(\tau_s(i))^2, \quad s = \{x,\ y,\ p\} \tag{19}$$

where: τ_s – control signal from regulator in the particular channel,
T = 1000, 1400, 2800 successively for first, second and third example.

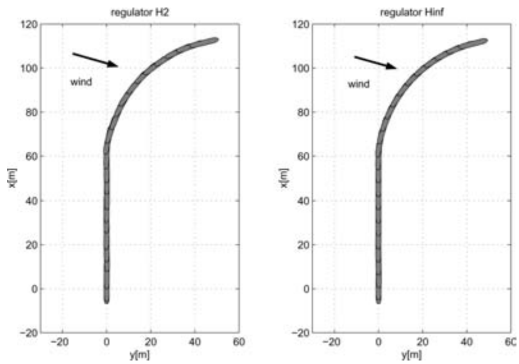

Figure 15. The trajectory of the ship in the second example drawn by silhouettes every 60[s]. Initial heading $\psi_0 = 0[deg]$, the trial period $t = 1400[s]$. An arrow indicate the average wind direction

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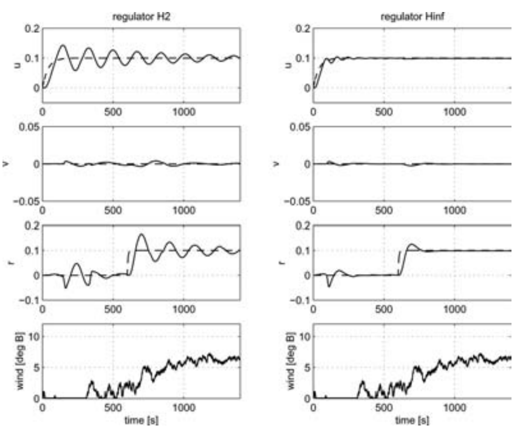

Figure 16. The velocities of the ship in the second example – from the top: surge, sway and yaw. The bottom figures present the wind speed in Beaufort scale (recalculated in the ship model scale 1:24). Solid lines denote real values, dashed lines – commands.

The results are presented in the tables:

Example 1

Controller	$J_{\tau x}$	$J_{\tau y}$	$J_{\tau p}$
H_2	30	805	34
H_{inf}	6	728	1

Example 2

Controller	$J_{\tau x}$	$J_{\tau y}$	$J_{\tau p}$
H_2	393	7	225
H_{inf}	180	5	132

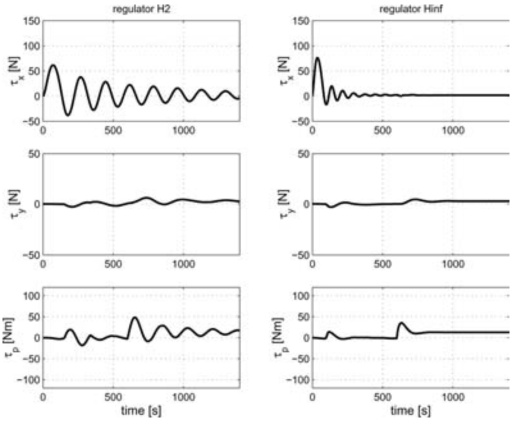

Figure 17. The commands from controllers – from the top: for surge – τ_x, for sway – τ_y and for yaw – τ_p.

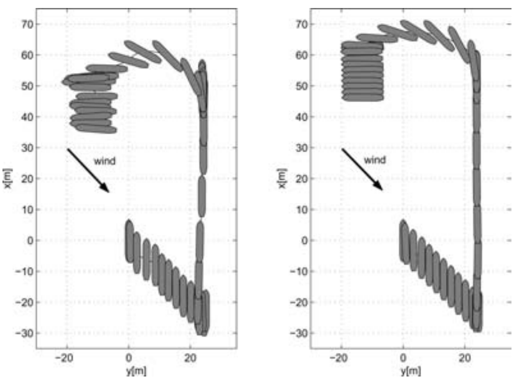

Figure 18. The trajectory of the ship in the third example drawn by silhouettes every 60[s]. Initial heading $\psi_0 = 0[deg]$, the trial period $t = 2800[s]$. An arrow indicate the average wind direction

.

Example 3

Controller	$J_{\tau x}$	$J_{\tau y}$	$J_{\tau p}$
H_2	7220	723	1104
H_{inf}	5120	444	633

Remarks

- The fully coupled, simulation model of the ship with acceptable accuracy gives possibilities to perform the identification trials instead of costs and time consuming full-scale experiments. One can the build the multidimensional linear model and estimate the system uncertainties: their ranges and sources, based on the results from simulation runs.
- The introduction of parametric uncertainties into the plant model enables to cover the changes of object characteristics (even nonlinear) in the all range of assumed work conditions. On the other hand it

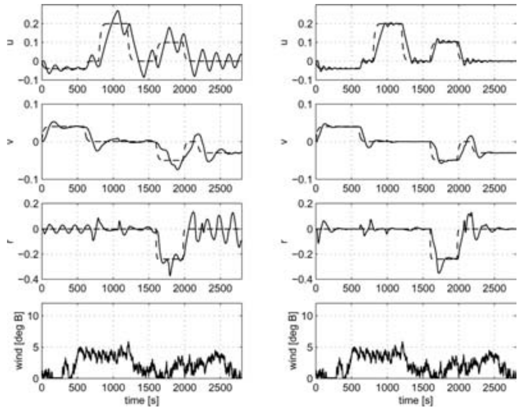

Figure 19. The velocities of the ship in the third example – from the top: surge, sway and yaw. The bottom figures present the wind speed in Beaufort scale (recalculated in the ship model scale 1:24). Solid lines denote real values, dashed lines – commands.

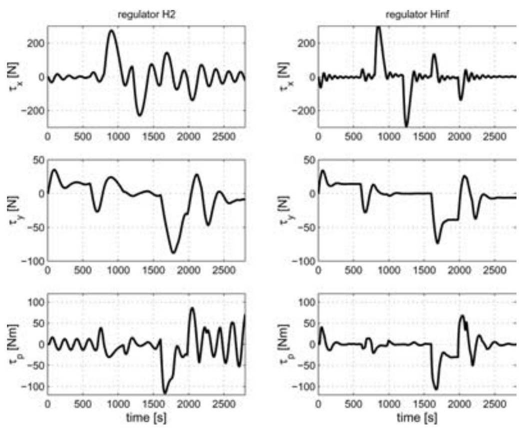

Figure 20. The commands from controllers – from the top: for surge – τ_x, for sway – τ_y and for yaw – τ_p.

causes the increasing difficulty in the controller synthesis.
- Very important advantage (or attribute) of both regulators is its fixed structure and constant values of coefficients. It means that navigators do not need to adjust any coefficients of these controllers.
- The H_2 controller works worse than the robust one. One can compare tables with results for control quality and steering effort. One of the main reasons for such a steering can be the lack of the robust properties of the regulator (see the H_{inf} norm of this regulator).
- Both systems were tested in the presence of a medium level of wind, in spite of fact that external disturbances were not taken into account during controllers synthesis processes. The robust regulator still seems to be a better one in such work conditions. The external disturbances one can try to introduce into the controller synthesis process but often no

enough adequate regulator is obtained (eg. without robust properties).

- As one can see in Fig. 12 – Fig. 19, the steering is almost de-coupling despite the full matrices B, C and D in the controllers.
- The both closed-loop systems are stable under all tested work conditions.
- The most important problems are related to yaw steering (especially for H_2 controller). One of the possible sources was the gyrocompass (with its accuracy 0.2[deg]) and one was the fact that the training ship is high weatherly.
- In general regulator calculated for one ship can not be transferable to another one due to linear object model specified for particular ship. It is a similar situation like with PID controllers in many industrial processes. But the possibility of using a simulation model of the ship's dynamics instead a real ship for experiments for H_2 or H_{inf} robust controller synthesis seems to be a great advantage of described approach.

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12.6
Speciation of population in neuroevolutionary ship handling

M. Łącki
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: This paper presents the idea of using machine learning techniques to simulate and demonstrate learning behavior in ship maneuvering. Simulated helmsman is treated as an individual in population, which through environmental sensing learns itself to navigate through restricted waters selecting an optimum trajectory. Learning phase of the task is to observe current situation and choose one of the available actions. The individual improves his fitness function with reaching destination and decreases its value for hitting an obstacle. Neuroevolutionary approach is used to solve this task. Speciation of population is proposed as a method to secure innovative solutions.

1 ARTIFICIAL INTELIGENCE IN DECISSION MAKING SUPPORT

1.1 *Introduction*

In Artificial Intelligence (AI) one of the main tasks is to create intelligent agents that adapt to current situation, i.e. change their behavior based on interactions with the environment (Fig 1.), becoming more efficient over time, and adapting to new situations as they occur.

Such ability is important for simulating helmsman behavior in ship maneuvering on restricted waters.

Learning process for simpler layouts can be performed using classic approach, i.e. Temporal Difference Reinforcement Learning (Tesauro 1995) or Artificial Neural Networks with fixed structures (Braun & Weisbrod 1993). Dealing with high-dimensional spaces is a known challenge in Reinforcement Learning approach which predicts the long-term reward for taking actions in different states (Sutton & Barto 1998).

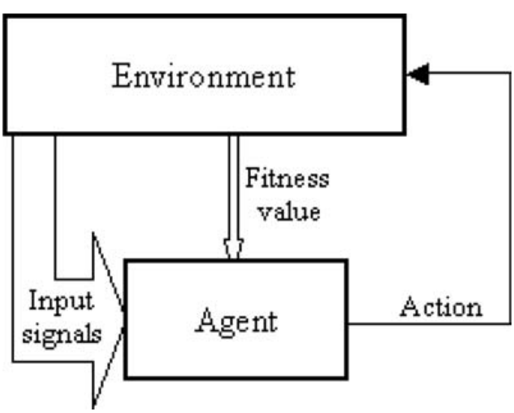

Figure 1. General model of agent-based systems.

1.2 *Reinforcement Learning approach*

Reinforcement Learning algorithms were taken into consideration in previous research studies by the author (Łącki 2007). In this approach the agent receives description of current situation from the environment and chooses one of available actions. Environmental situation, which should fundamentally affect agents' behavior, is described by actual state and signal called reward. The agents' goal is to maximize total amount of reward collected over time. In simpler case total accumulated reward is a sum of immediate rewards received in every time step. Unfortunately the results of extensive simulations were insufficient in high-dimensional environment, such as helmsman behavior in ship maneuvering on restricted waters. Since simulated model of environment consist only one active agent at a time, the overall learning speed was rather slow. It has occurred that the state space was too huge to allow the agent to learn effectively. Coarse coding of states (Sutton 1996) and simplification of state vector has speeded up learning process. At the same time inaccuracy in model of restricted waters environment increases. In the long run the agent was able to take the proper action to actual task but had to learn correct behavior for slightly different task by searching whole state space again. Due to limited computer resources the state space boundaries must be defined at the beginning of simulation. Furthermore to improve state-action pair value backups in episodic learning process the eligibility traces where used, which also requires additional memory resources.

In advanced tasks, particularly those with continuous hidden states and high-dimensional spaces,

Figure 2. Model of restricted waters environment.

Figure 3. Multi-agent simulation system. Helmsmen compete with each other simultaneously to find the optimum route to goal.

evolutionary approach to artificial neural networks, has proven to be more efficient.

1.3 *Neuroevolutionary approach*

Neuroevolution is evolving neural networks, both connection weights and structure, with genetic algorithms. The main idea of using evolutionary neural networks (ENNs) in ship handling is based on training population of helmsmen (Łącki 2008).

The neural network is the helmsman's mind allowing him to make decisions based on actual navigational situation which is represented by input signals received from environment. In each step the network calculates its output from signals received. These input signals are calculated from current situation of the environment, in this case: vessel in a confined area.

Neural network output value is the rudder angle. In actual evaluation there is only single output. Its value, which is calculated through evolution process of individuals in population, is normalized to rudder angle range from −35 degrees (port) to 35 degrees (starboard). There are plans to introduce several neural network outputs with normalization in order to bring the approach close to neural network decision support systems.

Classic artificial neural networks are not adequate in dynamic environment. Ship handling in restricted waters requires efficient network topology of helmsman's mind. To create such structure appeared to be a difficult task. The main cause of this difficulty comes from unknown hidden states and abundant variety of input signals. Furthermore evolutionary approach to neural networks is multi-agent system. It means that there are autonomous units searching for optimal solution simultaneously (Fig. 3).

In agent-based systems most important is to define proper state vector from available data signals derived from environment. It is also crucial to determine fitness function values received by the agent (Łącki 2008). Fitness calculation is of primary meaning when determining the quality of each individual. Subsequently it defines helmsman's ability to avoid obstacles while sailing toward designated goal.

The fitness value of an individual is adjusted in two ways: from arbitrary set action values and from calculated values, i.e.: distance to goal, relative heading to goal, distance to closest obstacle, etc.

Subjectively assigned action values are as follows: −1 if action leads to increase of the distance to goal in every time step, −10 when the ship is on the collision course (with an obstacle or shallow waters), +10 when she's heading to goal without any obstacles on course, −100 when she hits an obstacle or run aground, +100 when ship reaches a goal and −100 when she depart from the area in any other way, etc;

To simplify calculations ship's dynamic was reduced. For example speed of the ship remains constant despite significant radar deflection.

1.4 *Multi-criteria input signals*

Evaluation of quality of a state is to be treated as multicriteria problem. Its aim is to estimate a risk factor of getting stranded, getting too close to the shore, encountering a vessel with dangerous cargo, etc. It can be estimated by function of ship's position, course and angular velocity and information gained from other vessels (if considered in the model) and coastal operators. One of the efficient methods to estimate value of risk factor is Fuzzy TOPSIS (Filipowicz, Łącki & Szłapczyńska 2005).

TOPSIS stands for Technique for Order Preference by Similarity to an Ideal Solution. Was originated by Hwang and Yoon as a new multi-attribute decision making (MADM) method in 1981. Initially the approach was intended for crisp values then extended for fuzzy parameters (Chu & Lin 2003).

The main concept of this method is based on distance calculation. The best alternative among the available set is the closest to the best possible solution and the farthest from the worst possible solution simultaneously. The best possible solution, referred to as an ideal one, is defined as a set of the best attribute values, whereas the worst possible one, referred to as a negative-ideal solution, is a set of the worst at-tribute values. In this method every criteria is of benefit or cost type. In the discussed problem distance to closest obstacle is benefit criteria (should be kept as high as possible), while probability of encountering a vessel with dangerous cargo is a cost one (therefore is to be as low as justified).

The final TOPSIS ranking is created by sorting the coefficient values assigned to each of the alternatives in descending order. The alternative with the highest ranking value claims to be the best one.

When vessels hits an obstacle or depart from the area in forbidden way then its position is reset to initial values and the helmsman receives negative points to his fitness value. The ones that reach the goal reset their positions to initial ones and increases helmsmen fitness values respectively. Therefore, after several dozen of episodes there will be some of the individuals distinguished by their high fitness values.

The main goal of the individuals in population is to maximize their fitness values. This value is calculated from helmsman behavior during simulation as described above. The best-fitted individuals become parents for next generation.

Offspring genome is calculated from parents' genomes using evolutionary operations.

2 EVOLUTIONARY OPERATIONS IN NEAT NETWORKS

Neuroevolutionary systems are based on Topology and Weight Evolving Artificial Neural Networks (TWEANNs). These neural networks have the disadvantage that the correct although simplified topology need not be known at the beginning – it will evolve through evolutionary operations.

Among TWEANNs there is Neuro Evolution of Augmenting Topologies (NEAT). It is unique in that it begins evolution with a population of minimal networks and adds nodes and connections to them over generations, allowing complex problems to be solved gradually based on simple ones (Stanley & Miikkulainen 2002). This way, NEAT searches through a minimal number of weight dimensions and finds the appropriate complexity level of network topology adjusted to the problem. This process of complexification has important implications on search patterns. It may not be practical to find a solution in a high-dimensional space by searching in that space directly. But it may be possible to find solution by searching in lower dimensional spaces and further transfer of the best solutions into the high-dimensional space.

The NEAT network delivers solutions to three fundamental problems in evolving artificial neural network topologies:

- Innovation numbers line up genes with the same origin to allow disparate topologies to cross over in a meaningful way (innovation number is a unique value assigned to a new gene).
- Separation of each innovation into a different species protects its disappearing from the population prematurely.
- Start from a minimal structure, add nodes and connections, incrementally discovers most efficient network topologies throughout evolution.

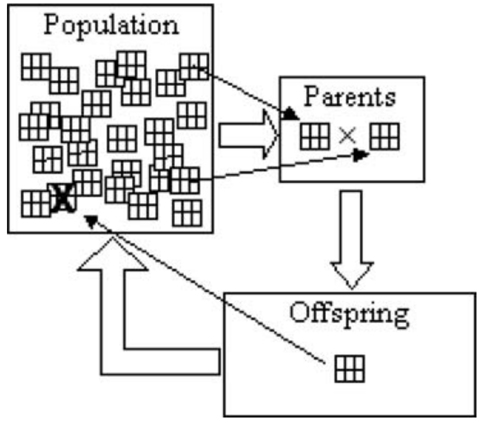

Figure 4. Evolution in population without species.

2.1 *Selection*

There are many ways to select individuals to become potential parents for next generation. Replacing the entire population on each generation may cause fast convergence to local extremes since there is strong selection method causing that everyone's genome would likely be inherited from best fitted individual. In addition, behaviors would remain static during the large gaps of time between generations.

The alternative is to replace a single individual every few time intervals as it is done in evolutionary strategy algorithms (Beyer & Schwefel 2002).

The worst individual, the one with lowest fitness value, is removed and replaced with an offspring of parents chosen from among the best. This cycle of removal and replacement happens continually throughout the simulation (Fig. 4).

2.2 *Crossover*

Every time a new connection gene appears in genome, what can only happen with mutation, a unique value is assigned to this gene called innovation number. Through innovation numbers, the system knows exactly which genes match up with another. The numbers are inherited and during crossover remain? unchanged, and allow algorithm to perform evolutionary operations without the need for expensive topological analysis. Genes that do not match are either disjoint or excess, depending on whether they occur within or outside the range of the other parent's innovation numbers.

During crossover the genes with the same innovation numbers are lined up. The connection weights of matching genes are averaged.

The disjoint and excess genes are inherited from the more fit parent or, if they are equally fit, from both parents. Disabled genes have a chance of being re-enabled during crossover, allowing networks to make use of older genes once again.

2.3 *Mutation*

Mutation is the main evolving mechanism in evolutionary neural networks. It can change both network topology and connection weights.

Connection weights mutate as in any neuroevolutionary systems, with each existing connection between nodes either affected or not.

Structural mutations, which form the basis of network complexity, occur in three ways. Each mutation expands the size of the genome by adding genes. In the add connection mutation, a single new connection gene is added connecting two previously unconnected nodes. In the add node mutation, an existing connection is split and the new node placed where the old connection used to be. The old connection is disabled and two new connections are added to the genome. In the add layer mutation, a new layer is created, if the maximum layer number has not been reached yet. After that there is possibility to evolve new nodes in that new layer by add node mutation.

There are also mutations removing connections, nodes and layers and special mutation disabling particular node. This node can be re-enabled in future mutations. Probability of each type of mutation is obviously different but its value is of primary meaning in efficient evolution.

3 SPECIATION

Speciation can be seen as a result from the same process as adaptation: natural selection exerted by interaction among organisms, and between organisms and their environment. Divergent adaptation of different populations would lead to speciation.

In the course of the modern synthesis in the 20th century a somewhat different view emerged that considered speciation and divergent adaptation, the two separate processes required for the origin of species diversity, mainly as resulting from different and unrelated mechanisms. Speciation of the population assures that individuals compete primarily within their own niches instead of competition within the whole population (Stanley & Miikkulainen 2005). In this way topological innovations are protected and have time to optimize their structure before they have to compete with other niches in the population.

3.1 *Algorithm*

When new individual appears in population, it must be assigned to one of the existing species or, if it is too innovative comparing to any other individuals, new species is created. The whole species assigning algorithm is presented below.

```
Begin of the Genome Loop:
   Take the next genome g from population P;
   Begin of the Species Loop:
      If all species in S have been checked:
         create new species s_new and place g in it;
      Else
      Get the next species s from S;
      If g is compatible with s, add g to s;
      If g has not been placed:
         continue the Species Loop;
      Else exit the Species Loop;
   If not all genomes in G have been placed:
      continue the Genome Loop;
   Else exit the Genome Loop;
```

Compatibility of genome g with species s is estimated accordingly to value of distance δ between two individuals which is calculated with formula 1:

$$\delta = \frac{c_1 E}{N} + \frac{c_2 D}{N} + c_3 \overline{W} \quad (1)$$

where: c_1, c_2, c_3 – weight (importance) coefficients; E – number of excesses; D – number of disjoints; W – average weight differences of matching genes; N – the number of genes in the larger genome.

If $\delta \leq \delta_t$, a compatibility threshold, then genome g is placed into this species.

One can avoid the problem of choosing the best value of δ by making δ_t dynamic. The algorithm can raise δ_t if there are too many species in population, and lower δ_t if there are too few.

3.2 *Fitness sharing*

Fitness sharing means that organisms in the same species must share the fitness of their niche. Thus, a species cannot afford to become too big even if many of its individuals perform well.

Therefore, any one species is unlikely to take over the entire population, which is crucial for speciated evolution to maintain topological diversity. The adjusted fitness f_i' for individual i is calculated according to its distance δ from every other individual j in the population:

$$f_i' = \frac{f_i}{\sum_{j=1}^{n} sh(\delta(i,j))} \quad (2)$$

The sharing function sh is set to 0 when distance $\delta(i,j)$ is above the threshold δ_t; otherwise, $sh(\delta(i,j))$ is set to 1 (Spears 1995). Thus, sum of sh calculates the number of organisms in the same species as individual i. This reduction is natural since species are already clustered by compatibility using the threshold δt. A potentially different number of offspring is assigned to every species. This number is proportional

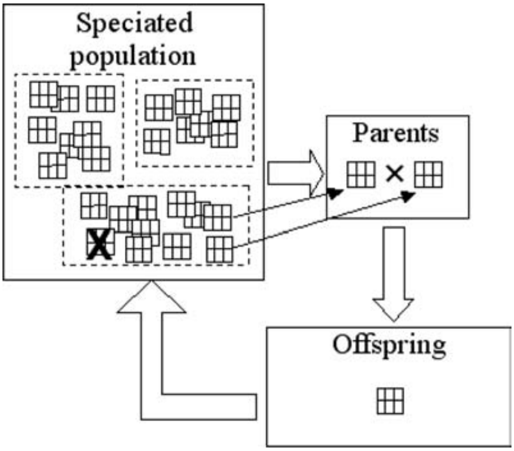

Figure 5. Evolution within one species in speciated population.

to the calculated sum of adjusted fitness values f_i' of its members.

Species reproduce by first eliminating the lowest performing members from the population. In the next step the entire population is replaced by the offspring of the remaining organisms in each species (Fig. 5). The other selection methods in speciated population are also considered in future research, i.e. island selection or permanent isolation of best fitted individuals of every species with particular task.

The final effect of speciating the population is that structural innovations are protected.

4 REMARKS

Speciation of population in neuroevolutionary machine learning can effectively improve learning process and decision making support in ship handling. Artificial neural networks with evolving topology and weights based on modified NEAT networks can increase learning speed of helmsmen. Complexity of considered model of ship maneuvering in restricted waters environment does not affect learning process very much. It is possible to use simulation models with much larger state space than it was possible in classic state machine learning algorithms without neural network function approximations (Kaelbling, Littman & Moore 1996). Issues like different selection methods of best fitted individuals, input signals encoding, splitting one output to several neural network outputs with normalization of signal values are also worth to be revised in future research in area of artificial intelligence support towards ship handling.

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12.7 Equalization of the measurements of the altitude, the azimuth and the time from observation of passages of celestial bodies

P. Bobkiewicz
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The article is describing the computational model serving equalization of the astronomical measurements accomplished to navigational and geodetic purposes. Series of measuring data: the altitude, the azimuth and the time from observation of passing of celestial bodies in the field of view of the observing device are input parameters to calculations. This data is burdened with random error of the measurement. The equation of the movement of celestial body in the horizontal system is the result of the equalization. It is possible to calculate the azimuth and the altitude for the chosen moment or to fix the time of the given azimuth or the altitude from this equation.

1 INTRODUCTION

Assuming, that the movement of celestial bodies on celestial sphere results only from rotary motion of the earth, then these bodies are moving along circles, which center is in the vicinity of closer pole and their radius is equal to the complement of the declination to the right angle. This assumption is correct during navigational or geodetic measurements due to short time of their duration. When the low accuracy of measurement is allowed (for example for the purposes of celestial navigation accuracy of altitude of 0.1′ and accuracy of time of 1 second is required), then measuring series compound of several measurements of the altitude or the azimuth and the time can be equalized with straight line. The correction for the curve of celestial latitude is taken into account in such series in methods of the astronomical geodesy, and thanks to this it is possible to treat these series as linear in relation to the center thread. Both mentioned methods of the processing of measuring data results from the tendency of reduction of the amount of calculations connected with their processing. In the case, when measuring data is processed automatically, for the equalization one can accept the path of celestial body along circle and derive equation of the movement of the body in horizontal coordinates system (approximating equation). And then choose any location of the body on the circle, which data will be put to the reduction father.

2 APPROXIMATING EQUATION IN THE FIELD OF VIEW

Celestial bodies in their daily movement should theoretically form the arcs of the small circles on the celestial sphere with radiuses equal to the complement of the declination δ to the right angle and with centers in the closer celestial pole. In the particular case, when the body lies on the celestial equator it is great circle and the path of the body form straight line. The real path is influenced additionally by: the change of refraction with the altitude of the body and oscillations of its image, and at the measurements random errors of the measurements. One uses series n of the measurements of the position of celestial body: zenith distance z_i, the azimuth a_i and the time of registration t_i appropriate for point P_i, for derivation of equation of the movement. Zenith distances z_i have to be corrected for the refraction $r(z_i^r)$ appropriate for z_i^r

$$z_i = z_i^r + r_i\left(z_i^r\right). \tag{1}$$

The variable z_i^r is measured and burdened with refraction, and z_i already corrected for the value of refraction.

The approximating equation is described by horizontal coordinates z_P (zenith distance) and a_P (azimuth) of the center P of circle along which body moves, with its radius r equal in first approximation of its polar distance

$$r = \pi / 2 - \delta \tag{2}$$

and by horizontal coordinates z_G and a_G and time t_G of indicated point P_G on this circle (Fig. 1). The point P should theoretically agree with the pole which is nearest to the celestial body. Additional parameters of which values are known these are a declination δ of celestial body and an angle speed of change of right ascension v_{max} equal 7,29212E-05 radian for a second result from rotation of the Earth.

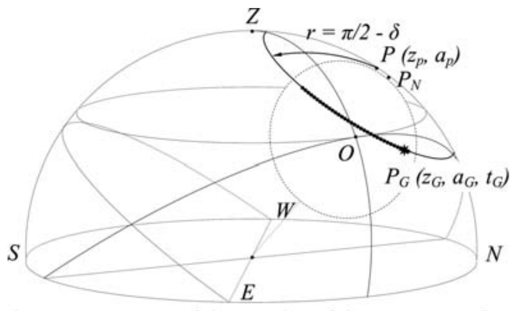

Figure 1. Parameters of the equation of the movement of celestial body in the horizontal system: circle with radius r and with centre in the point P as well as point P_G on this circle and time t_G appropriate to this point.

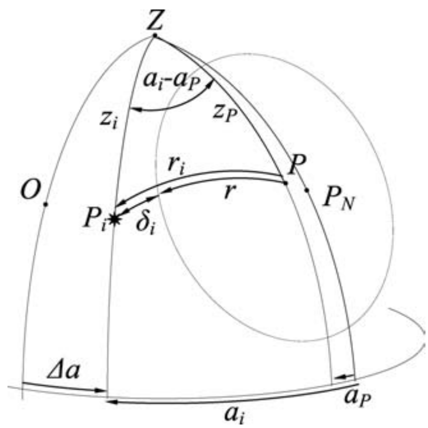

Figure 2. The shortest great circle distances δ_i between the point P_i and the circle with centre in the point P.

2.1 *Determination of the centre of the circle $P(z_P, a_P)$*

By the means of least square roots method, one seek such point P on the spherical surface, so that the sum Δ of square roots of the shortest great circle distances δ_i between respective point $P_i(z_i, a_i)$ and circle with the centre in the point P is minimal

$$\Delta = \sum_{i=1}^{n} \delta_i^2 = \min . \tag{3}$$

The function of distance δ_i is difference of radius r and distance r_i of given point P_i from centre of circle P (Fig. 2)

$$\begin{aligned} \delta_i &= r - r_i \\ \delta_i &= r - \arccos(\cos z_i \cos z_P + \sin z_i \sin z_P \cos(a_i - a_P)) \end{aligned} \tag{4}$$

The condition (3) is met if derivatives of variables z_P and a_P are equal 0

$$\sum_{i=1}^{n} \frac{\partial \delta_i^2}{\partial z_P} = 0, \quad \sum_{i=1}^{n} \frac{\partial \delta_i^2}{\partial a_P} = 0 . \tag{5}$$

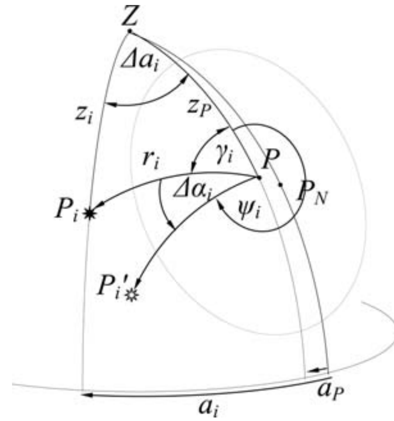

Figure 3. Reduction of points P_i to time t_G by the rotation of points around P for the angle of the change of right ascension $\Delta\alpha_i$.

Differentiating (4) through variables z_P and a_P, substituting to (5) and summing up for all points we receive a pair of non-linear equations with two unknown quantities z_P and a_P. It is possible to solve the pair of equations with iteration method taking horizontal coordinates of the pole nearest to celestial body as first approximation of the centre. We receive values in demand z_P and a_P in the result of the solution of the pair of equations.

2.2 *Reducing measurements to time t_G*

Each point P_i is reduced to any chosen time t_G. This reduction is made by the rotation of the point around determined centre of the circle for the angle $\Delta\alpha_i$ of the change of the right ascension for the difference of time Δt_i between times t_G and t_i (Fig. 3)

$$\begin{aligned} \Delta t_i &= t_G - t_i \\ \Delta\alpha_i &= v_{\max} \cdot \Delta t_i \end{aligned} . \tag{6}$$

It is necessary to calculate angle γ_i and distance r_i shown on figure 3 to determine coordinates of reduced point $P_i'(z_i', a_i')$. Defining the angle Δa_i as

$$\Delta a_i = a_i - a_P \tag{7}$$

and keeping its value in the range $(0, 2\pi)$, then γ_i and r_i are calculated from formulae

$$\begin{aligned} \cos r_i &= \cos z_i \cos z_P + \sin z_i \sin z_P \cos(\Delta a_i) \\ \cos \gamma_i &= \frac{\cos z_i - \cos z_P \cos r_i}{\sin z_P \sin r_i} \end{aligned} , \tag{8}$$

in addition for $\Delta a_i < \pi$

$$\gamma_i = 2\pi - \gamma_i . \tag{9}$$

Defining the angle ψ as

$$\psi_i = \gamma_i + b \cdot \Delta\alpha_i \tag{10}$$

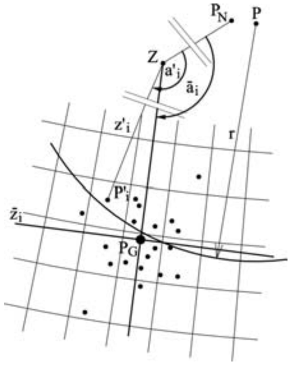

Figure 4. Point P_G calculated as the average of reduced points $P_i'(z_i', a_i')$.

where b is equal 1 for P lying near north pole and -1 for south pole, and then keeping its value in the range $(0, 2\pi)$, z_i' and a_i' of reduced point P_i' are calculated from formulae

$$\begin{gathered}\cos z_i' = \cos z_P \cos r_i + \sin z_P \sin r_i \cos(\psi_i) \\ \cos \Delta a_i' = \frac{\cos r_i - \cos z_P \cos z_i'}{\sin z_P \sin z_i'}\end{gathered}, \qquad (11)$$

in addition for $\psi_i < \pi$

$$\Delta a_i' = 2\pi - \Delta a_i' \qquad (12)$$

and then

$$a_i' = a_P + \Delta a_i'. \qquad (13)$$

2.3 *Determination of the point $P_G(z_G, a_G)$ on the circle for the time t_G*

Point P_G is made by averaging coordinates of reduced points $P_i'(z_i', a_i')$ (Fig. 4).

Assuming that P_G is in the considerable distance from the Zenith and from the Nadir compared with the error of position of P_i', then the mean zenith distance and mean azimuth are calculated from formulae

$$\bar{z} = \sum_{i=1}^{n} z_i' \quad \bar{a} = \sum_{i=1}^{n} a_i'. \qquad (14)$$

The standard deviation of position of the measurement point along the vertical circle σ_z, along almucantar σ_l and on the plane m_i are calculated from

$$\begin{gathered}\Delta z_i = \bar{z} - z_i' \quad \Delta a_i = \bar{a} - a_i' \\ l_i = \Delta a_i \cdot \sin \bar{z} \\ \sigma_z = \sqrt{\frac{\sum_{i=1}^{n} \Delta z_i^2}{n-1}} \quad \sigma_l = \sqrt{\frac{\sum_{i=1}^{n} \Delta l_i^2}{n-1}} \\ m_i = \sqrt{\sigma_z^2 + \sigma_l^2}\end{gathered} \qquad (15)$$

and the standard deviation of position of P_G on the plane

$$m = \frac{m_i}{\sqrt{n}}. \qquad (16)$$

Function (3) of determining of the centre P of the circle is sensitive in the square roots of the distance between the point P_i and the arc of the circle but the point P_G is calculated as the average (14), it is proportionally to the distance from mean point, so the point P_G doesn't lie on the circle (Fig. 4). One can move this point onto the circle, by projection along radius r. Or one can determine new radius r' and new angle γ' from (17), assuming that the arithmetic mean is a better estimator for the measurement of passage of celestial bodies then the square roots average.

$$\begin{gathered}\Delta a = a_G - a_P \\ \cos r' = \cos z_G \cos z_P + \sin z_G \sin z_P \cos(\Delta a) \\ \cos \gamma' = \frac{\cos z_G - \cos z_P \cos r}{\sin z_P \sin r}\end{gathered} \qquad (17)$$

For $\Delta a < \pi$ from (17) (value Δa kept in the range $(0, 2\pi)$)

$$\gamma' = 2\pi - \gamma'. \qquad (18)$$

3 DETERMINATION OF TIME AND COORDINATES FROM THE EQUATION OF THE MOVEMENT

3.1 *Calculation of coordinates on the circle for the given time t_i*

Having the point P_G with coordinates z_G and a_G and its time t_G on the circle with the centre in the point $P(z_P$ i $a_P)$ and with radius r', it is possible to determine coordinates z_i and a_i of the other point P_i on this circle for any given time t_i, the same way as measurement points were reduced to time t_G – formulae (6), (10)–(13). Appropriate formulae have the form

$$\begin{gathered}\Delta t_i = t_i - t_G \\ \Delta \alpha_i = v_{\max} \cdot \Delta t_i\end{gathered}, \qquad (19)$$

$$\psi_i = \gamma' + b \cdot \Delta \alpha_i, \qquad (20)$$

$$\begin{gathered}\cos z_i = \cos z_P \cos r' + \sin z_P \sin r' \cos(\psi_i) \\ \cos \Delta a_i = \frac{\cos r' - \cos z_P \cos z_i}{\sin z_P \sin z_i}\end{gathered}, \qquad (21)$$

in addition for $\psi_i < \pi$

$$\Delta a_i = 2\pi - \Delta a_i, \qquad (22)$$

$$a_i = a_P + \Delta a_i. \qquad (23)$$

3.2 *Calculation of the time t_i of reaching the zenith distance z_i*

Converting (21) with taking into consideration (20) and (19), it is possible to calculate the appropriate time t_i for any given zenith distance z_i. ψ value from formula

$$\cos\psi = \frac{\cos z_i - \cos z_P \cos r'}{\sin z_P \sin r'} \quad (24)$$

corresponds with two values of the angle ψ_i from the formula (20)

$$\begin{aligned}\psi_{i1} &= \psi \\ \psi_{i2} &= 2\pi - \psi\end{aligned}, \quad (25)$$

so substituting each of them to

$$t_i = \frac{\psi - \gamma'}{b \cdot v_{\max}} + t_G \quad (26)$$

we receive two values t_i. There is no solution of the equation (24) for $z_i < |z_P - r'|$ and $z_i > |z_P + r'|$. Exchanging inequalities for equalities above formulae describe conditions, by which (24) has only one solution.

3.3 *Calculation of the time t_i of reaching the azimuth a_i*

In order to calculate t_i appropriate to any given value a_i, it is necessary to determine from formula

$$\cos r' = \cos z_P \cos z_i + \sin z_P \sin z_i \cos \Delta a_i \quad (27)$$

involved value z_i, where Δa_i is calculated as (7). There is one (for the equality) or two solutions (for the inequality) of z_i in the case, when

$$\sin r' \geq= \sin z_P \sin \Delta a_i \quad (28)$$

or there is no solution in remaining cases. The farther proceedings comes down to the calculation of the time of reaching the obtained zenith distance z_i, which was descried higher. To the formula (26) one should substitute only one value calculated from the equation (25), that is ψ_{i2} for $\Delta a_i < \pi$, and ψ_{i1} in the opposite case.

Time t_i and coordinates z_i, a_i serve as data corrected for refraction for the reduction in various methods of making astronomical fix.

4 CONCLUSIONS

The described method of the equalization of measurements assumes that celestial bodies rotate on circles with constant speed and only random errors of measurement are found in measurement data. It is possible to determine data for the reduction for the any given point on the circle. If this point is in vicinity of the arc containing measuring data, then the accuracy of this point results directly from the accuracy of the measurement and the number of measurements.

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12.8
Programmatic correction of errors of measuring track processing

M. Luft, E. Szychta & R. Cioc
Technical University of Radom, Radom, Poland

ABSTRACT: A programmatic method of correcting errors of the measuring track is presented. Methods of determining transfer function of the measuring track are introduced and measurement results with and without the correction are compared.

1 INTRODUCTION

Elements of a typical measuring track include: measuring transducers, elements adapting the measurement signal to elements of the measurement system, analogue-digital transducers, filters, and elements processing and analysing measurement signals. A typical measuring track is shown in Fig. 1.

Vibration transducers are the initial track elements. Accelerometers are most commonly employed in diagnostics. A conditioning and amplifying system adapts the electrical signals from the transducer (reducing its great internal impedance) to the input of the analogue-digital transducer. A signal usually needs to be filtered to achieve its good quality, necessary for determination of vibration parameters (Szychta 2006). Data are then processed and analysed, compared with available standards, and the resultant output signal is displayed in the form of, for instance, a characteristic curve or tabulated results.

The output signal of a measuring track may be a signal used to control equipment, e.g. abrupt braking system, vehicle suspension, etc. In such circumstances, the basic criterion for real time controlling of this device is the correct processing of the input signal by the measuring transducer and sending of this signal to a control device over a time-span that allows the device to respond to the given situation. This implies correct choice of a transducer adapted to the input signal (the range of frequencies and sensitivities measured). It must be borne in mind that each element in a measuring track introduces errors and delays in processing of the measuring signal, often amplifying the errors introduced by the function of upstream elements of the measurement track. The processing time of a measurement signal by the track is important in applications that require rapid measurements. With the number of elements processing a signal, the time may be extended till a point when correct operation of a control system will no longer be possible.

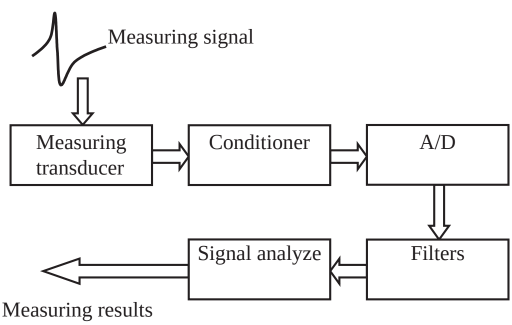

Figure 1. Typical measuring track.

2 TESTING OF THE MEASURING TRACK IN LABORATORY CONDITIONS

Figure 2 illustrates a diagrammatic measurement system used to test characteristics of measuring track processing. An accelerometer including an inbuilt DeltaTron preamplifier of sensitivity 10.18 mV/ms^{-2} (A2) and the range of measured frequencies 0.3 Hz to 6 kHz, and a conditioner of the operating range from 1 Hz to 20 kHz is the sensor under testing.

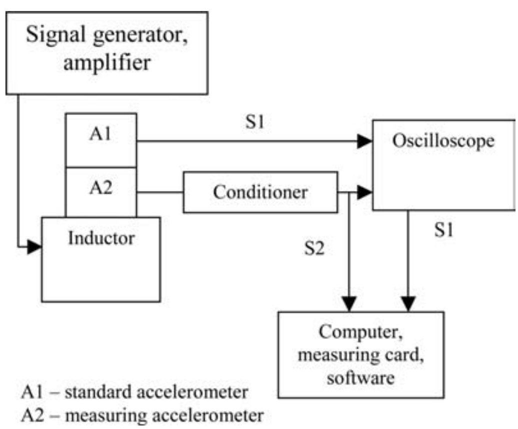

Figure 2. Flow diagram of a measuring track testing system.

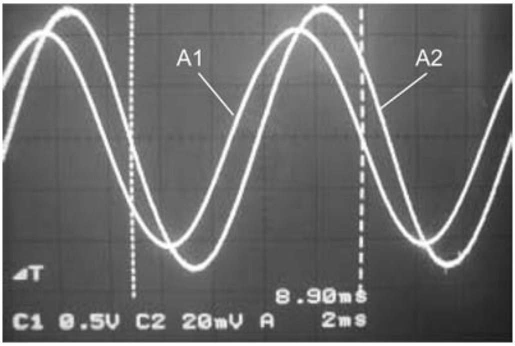

Figure 3. The courses of signals from the reference and measurement accelerometer.

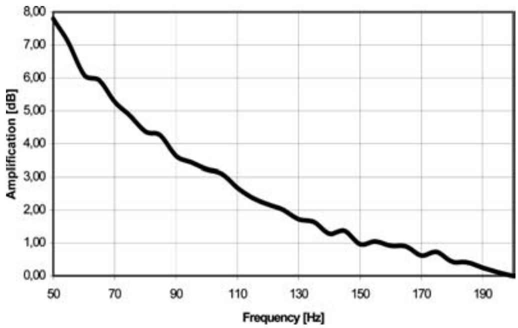

Figure 4. The attenuation diagram of the measuring sensor.

The reference value of acceleration is obtained from the accelerometer, whose sensitivity is much greater than that of the tested accelerometer and whose measuring signal can be read without the need for additional equipment. To this end, a piezoelectric accelerometer of sensitivity 317 mV/ms^{-2} (A1) and the range of measured frequencies from 50 to 200 Hz is used.

Figure 3 shows courses of signals from the accelerometers A1 and A2 for sinusoidal input function of frequency 100 Hz and acceleration amplitude of 3.15 m/s^2, as read from the course of the reference accelerometer A1. The delay between the signal from the accelerometer including the preamplifier A2 and the signal from the piezoelectric accelerometer A1 is 8.9 ms. The determined relative error between values of computed acceleration amplitudes is 40%. Measuring of the acceleration with the computer, measurement card (of sampling frequency 40 kHz), and the software cause a further delay of 1.1 ms between the measurements. The delay between measurement of the signal from the transducer A2 and A1 total 10 ms.

Figure 4 illustrates the attenuation diagram of the acceleration of the vibration transducer A2 as determined in testing. To enhance reliability of the results, the measurements were made in the frequency range of the correct operation of the reference transducer A1: 50 Hz–200 Hz. Technical specifications of A1 indicate that, in this range, the amplification of the output signal's amplitude in relation to the transducer's input signal is within ±1 dB. This is usually the acceptable value for purposes of measurements. Technical specifications of A2 state that, in the frequency range 0.3 Hz–6 kHz, the same value is ±10% and corresponds to ±0.91 dB. It was assumed that A1 relays the amplitudes closer to the actual values, as it is designed to operate in a narrower frequency range, at more than 30 times greater sensitivity, and without additional elements that would process, and affect, the measurement signal.

Accepting the amplification of ±1 dB in the frequency range 50 Hz–200 Hz, declared in the specification of A1, the resulting characteristic curve shows that the value of amplification of A2 is achieved in the range of frequencies above 125 Hz. This is different than the manufacturer's bottom value of 0.3 Hz.

To avoid problems of correct reading of the values measured by the transducers, particularly the reference transducer, assume the amplification range of correctly measured accelerations ±2 dB. The characteristic curve presented in figure 4 indicates this frequency is in the range 125 Hz–200 Hz.

3 CORRECTION ALGORITHM

Determination of a dynamic correction algorithm of a real measuring transducer requires knowledge of its dynamics in the form of differential equations and of the dynamics of the entire measurement system. Manufacturers' attempts at maintenance of transducers' reproduction properties in the manufacturing process have been a failure. Depending on the transducer class, the particular pieces and production lots suffer from some errors of reproduction, sensitivity, and processing range. Therefore, correction algorithms must always be determined for specific measuring transducers and measurement systems, and the resultant equations must only be applied to the particular sensors (Cioc 2006).

In measurements requiring highly accurate results, other measuring track elements (amplifiers, measuring cards, signal processing elements, etc.) should be taken into account when defining dynamic correction algorithms.

The need to consider elements other than the sensor itself when describing system dynamics is an initial difficulty with attempts to determine the correction algorithm. The signal from the reference transducer and from the measurement system need to be compared to describe the system's dynamics. ARX (AutoRegressive with eXternal input) method (Luft 2005) was employed to identify dynamic parameters of the measuring track. The voltage signal from the end of A2's measuring track is the identified signal, and voltage (S1), which is the response of the accelerometer A1 to sinusoidal input of 200 Hz, is the comparative (reference) signal. Acceleration values are determined on the basis of voltage signals from the sensors and

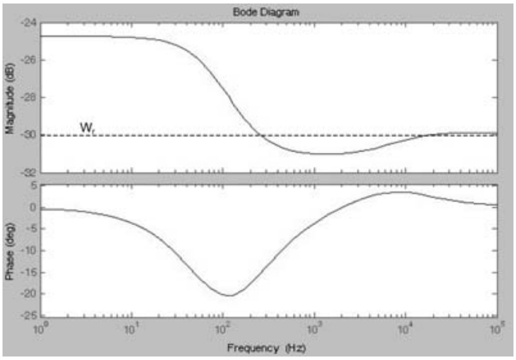

Figure 5. Frequency characteristic curves of a measuring track including an accelerometer.

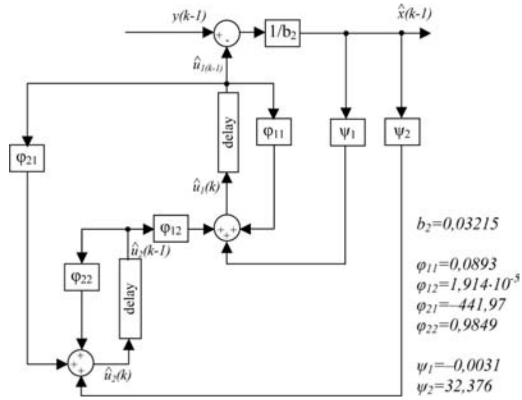

Figure 6. The flow diagram of the correction algorithm of the measuring accelerometer.

the latter's sensitivity. To limit the calculations and the processing time, the correction algorithm was assumed to estimate the voltage signal from the measuring transducer according to the algorithm parameters as determined by comparison of signals of the reference and measuring transducers.

Application of ARX produces the transfer function $G(s)$ which describes processing dynamics of the system: accelerometer – conditioner – measuring card – data acquisition software:

$$G(s)=\frac{0{,}03215s^2+1319{,}6s+1{,}338\cdot10^6}{s^2+4{,}678\cdot10^4s+2{,}309\cdot10^7} \tag{1}$$

Magnitude and phase characteristic curves of the transmittance system (1) are shown in Figure 5. A great amplification can be seen in the magnitude characteristic curve as sensors of varying sensitivities are applied to testing of the voltage signals. The reference amplification level is expressed as a relation of the measuring transducer's sensitivity to the sensitivity of the reference transducer on the logarithmic scale: $W_r = -29.87$ dB. Given this value, the relation of acceleration determined on the basis of the measuring sensor's voltage signal to the acceleration determined using the reference sensor is $a_{A1}/a_{A2} = 1$. The magnitude characteristic curve at the adopted boundary value of the amplification ± 2 dB W_r is in the frequency range over 117 Hz.

The dynamic correction algorithm for the transfer function (1) is expressed in a differential equation:

$$\frac{d^2}{dt^2}y+4{,}678\cdot10^4\frac{d}{dt}y+2{,}309\cdot10^7y= 0{,}03215\frac{dt^2}{dt^2}x+1319{,}6\frac{dt}{dt}x+1{,}338\cdot10^6x \tag{2}$$

where x = input quantity; y = output quantity.

The correction algorithm (Jakubiec 2000) for the measuring track's transfer function (2) and received digitisation time $Td = 0.05\,ms$ becomes a set of equations:

$$\begin{cases}\hat{x}(k-1)=\dfrac{1}{0{,}03215}\left[y(k-1)-\hat{u}_1(k-1)\right]\\ \hat{u}_1(k)=0{,}0893\cdot\hat{u}_1(k-1)+1{,}914\cdot10^{-5}\cdot\hat{u}_2(k-1)-0{,}0031\cdot\hat{x}(k-1)\\ \hat{u}_2(k)=-441{,}97\cdot\hat{u}_1(k-1)+0{,}9849\cdot\hat{u}_2(k-1)+32{,}376\cdot\hat{x}(k-1)\end{cases} \tag{3}$$

where $\hat{x}(k-1)$ = estimate of input quantity at moment $k-1$; $y(k-1)$ = measurement result at moment $k-1$; $\hat{u}_1(k)$, $\hat{u}_2(k)$ = variable at moment k.

The flow diagram of the correction algorithm described with (3) and illustrated in Figure 6 suggests that its correct function depends on correct determination of the factors of the discrete transducer model ϕ and ψ. These are constant for a specific digitisation time.

In the first step of the algorithm, it is necessary to adopt an initial value of the variable $\hat{u}_1(k-1)$. It was assumed to equal 0. In effect, the algorithm will operate correctly only after a correct variable $\hat{u}_1(k-1)$ is automatically determined. This takes several digitisation steps. Given the accelerometer manufacturers' recommendations to take measurements for several dozen seconds to several minutes after the system start-up, determination of an initial optimum value of $\hat{u}_1(k-1)$ is not necessary.

4 CORRECTION RESULTS

Figure 7 shows the waveforms of voltages and the resultant accelerations from the accelerometers in the measurement system illustrated in Fig. 4.2. The measurements were conducted at sinusoidal input of frequency 200 Hz – which is within the reading range of both the transducers (according to calibration cards of their manufacturers) and for which the input error, according to the magnitude characteristic curve in Fig. 4.4, becomes the lowest.

In this case, the delay between the waveforms obtained from the measuring (A2) and reference (A1) accelerometers is 5.3 ms. The acceleration magnitude,

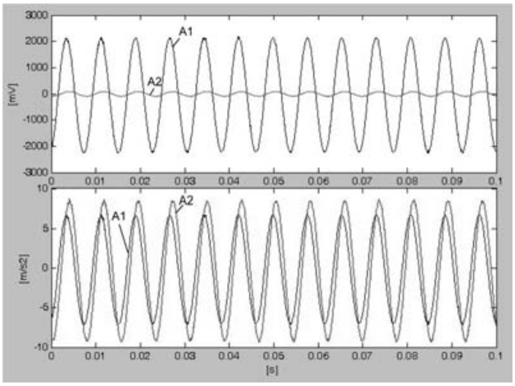

Figure 7. Voltage and acceleration waveforms for the reference and measuring accelerometer.

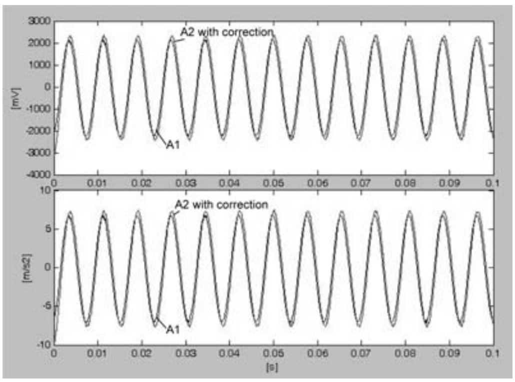

Figure 8. Voltage and acceleration waveforms for the reference and measuring accelerometer post the correction.

calculated as the mean value of absolute magnitudes in 2000 measurement samples, equals 7.01 m/s^2 for A1 and 9.05 m/s^2 for A2. This corresponds to a relative error in measurement of acceleration magnitude equal to 29.1%.

The correction algorithm estimates voltages from the measurement accelerometer and attempts to approximate their time waveform to the form obtained from the reference accelerometer. Correction of voltage characteristic curves of the measurement transducer in Figure 7 according to the algorithm (3), compared to the reference values obtained from A1, is shown in Figure 8. The delay between the waveform produced after estimation of the data from the measurement accelerometer A2 and the waveform from the reference accelerometer is 0.05 ms. This the time of signal sampling. This implies that the correction algorithm reduced the 5.3 ms delay between the reference and measurement transducer to the minimum possible value.

The delays resulting from computer mathematical calculations are negligible. They are not significant given the current computer capacities and the calculation simplicity of an algorithm which consists of five

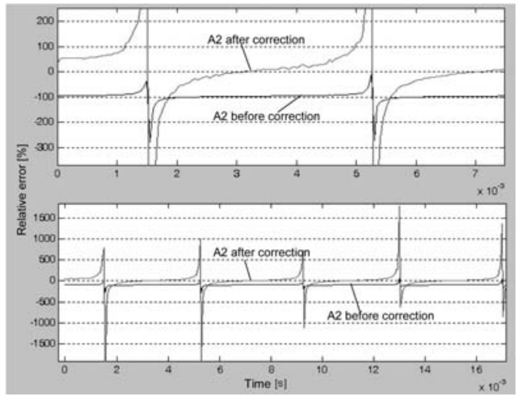

Figure 9. Characteristic curves of relative errors of accelerations measured using an accelerometer without and with a correction.

Table 1. Relative error values of an accelerometer without and with the correction.

Time [s]	0.002	0.0025	0.003	0.0035
Relative error of accelerometer A2 [%]	−102.13	−98.74	−97,37	−96.37
Relative error of accelerometer with the correction algorithm [%]	−66.09	−18.61	−2.61	9,03
Time [s]	**0.0040**	**0.0045**	**0.0050**	**0.006**
Relative error of accelerometer A2 [%]	−95.40	−93.86	−86.98	−100.08
Relative error of accelerometer with the correction algorithm [%]	17.24	32.06	111.86	−35.81

additions and seven multiplications only. An attempted measurement of the time taken for the algorithm calculations in MATLAB environment, Windows XP, the processor Intel Celeron 1.5 Ghz, and 512 MB of memory, produced results below 0.1 µs.

The mean magnitude of estimated acceleration of A2 for 2000 samples is 7.59 m/s^2. Compared to the magnitude of the reference accelerometer, the measurement relative error is 8.3% – which constitutes a three and half times reduction compared to the same error without applying the correction algorithm. Figure 9 illustrates the course of relative error values in respect of A2 accelerations using and not using the correction algorithm. The peak values in the characteristic curves result from the reference signal values approximating zero. Table 1 presents values of the relative error for an accelerometer employing and without employing the dynamic correction algorithm for a selected time range.

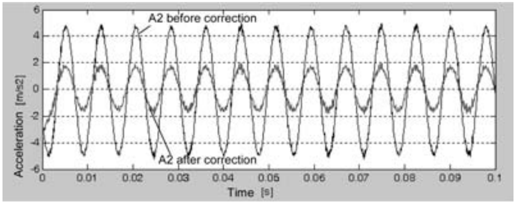

Figure 10. Characteristic curves of acceleration absolute errors as measured using an accelerometer with and without the correction.

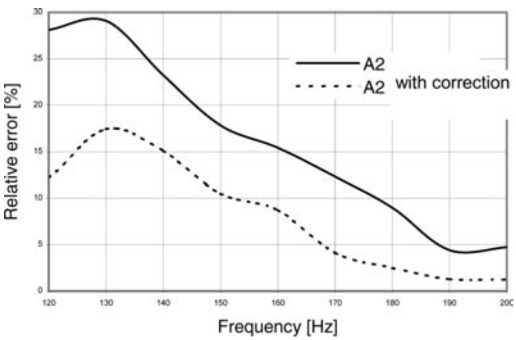

Figure 11. Relative error of the acceleration magnitude prior to and post the correction as dependent on frequency.

The mean relative errors at the waveform magnitudes are: −96.4% for the signal from the measuring transducer, and 23.1% for the estimated signal.

Figure 10 presents the characteristic curve of A2's absolute errors with and without the correction. The mean absolute error of A2's magnitude, determined as the absolute mean value of the magnitudes in 2000 samples, is $5.11\,m/s^2$. The same error in respect of measurements including the dynamic correction algorithm diminishes to $1.94\,m/s^2$. The great value of the absolute error, in the case of measurements both with and without the correction, is a result of the transducer's dynamic properties, i.e. a phase shift of measurands. The successive measurement values change too fast for the transducer's capability of reproducing the input magnitude. When the absolute error is determined, a measurand's waveform is shifted in relation to the actual value by a value determined by the transducer's frequency characteristic curve. The correction reduced the resultant absolute error by more than two and a half times.

Figure 11 plots the course of the absolute error of A2's acceleration magnitudes prior to and post the correction relative to the frequency of the sinusoidal input signal. At 200 Hz, where parameters of the correction algorithm were defined, the post-correction relative error of the acceleration reduces to a minimum, to rise as it diverges from this value. The minimum post-correction relative error of the acceleration is 1.2%, compared to 4.7% without the correction.

5 CONCLUSION

Accurate and fast measurements require corrections to be applied to the measuring track in order to reduce the measurement error. The programmatic correction method proposed by the authors significantly reduces errors and enables the measurement system to operate 'on-line'.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

12.9 Alternative for Kalman filter – Two dimension self-learning filter with memory

A. Fellner
Silesian University of Technology, Gliwice, Poland

K. Banaszek
Polish Air Navigation Services Agency, Warsaw, Poland

P. Tróminski
GNSS-Consortium, Poland

ABSTRACT: We propose new solution for idea Prof. Vanicek and Prof. Inzinga. This filter relies basically on the information contained in measurements on the vehicle: position fixes, velocities and their error statistics.

The basic idea behind this new navigation filter is twofold:

1 A cluster of the observed position fixes contains true kinematic information about the vehicle in motion,
2 A motion model of the vehicle associated with the error statistics of the position fixes should be able to get, to a large extent, the information out of the measurements for use.

We base the filter on an analogy. We consider the statistical confidence region of every position fix as "source" tending to "attract" the undetermined trajectory to pass through this region. With these position fixes and their error statistics, a virtual potential field is constructed in which an imaginary mass particle moves. To make the filter flexible and responsive to a changing navigation environment, we leave some parameters free and let the filter determine their values, using a sequence of observations and the criterion of least squares of the observation errors. We show that the trajectory of the imaginary particle can well represent the real track of the vehicle.

In our poster we presents basic idea this filter and numerical method for calculate best position using this filter also we show experiment (with RTK/SPAN technology) that we do for verification presented filter.

Filter function:

$$\Phi_{r^0} = \frac{1}{K}\exp\left[-\frac{1}{2}(r-r^0)^T C^{-1}(r-r^0)\right] \quad (1)$$

$r = \begin{bmatrix} x \\ y \end{bmatrix}$ position vector in actual time "t"

$r^0 = \begin{bmatrix} x^0 \\ y^0 \end{bmatrix}$ position vector in time "t_0"

$$K = (2\pi)^{\frac{3}{2}}(detC)^{\frac{1}{2}} \quad (2)$$

Where C is a matrix of covariance

$$C = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} = \begin{bmatrix} D^2X & cov(X,Y) \\ cov(Y,X) & D^2Y \end{bmatrix} \quad (3)$$

The basis for estimation position is potential U_i

$$U_i(t) = G(r-r^0)^T C_i^{-1}(r-r^0)e^{-\alpha(t-t_i)} \quad (4)$$

Next step is conversion U_i when we know "n" position before time "t"

$$U = \sum_{i=1}^{n} U_i = Ge^{-\alpha t}\sum_{i=1}^{n}(r-r^0)^T C_i^{-1}(r-r^0)e^{\alpha t_i} \quad (5)$$

$$U(t) = \sum_{i=1}^{n} U_i(t) = Ge^{-\alpha t}\sum_{i=1}^{n}\left[\frac{(x-x_{0i})^2}{\sigma_{11i}^2} + \frac{(y-y_{0i})^2}{\sigma_{22i}^2}\right]e^{\alpha t_i} \quad (6)$$

where $r = \begin{bmatrix} x \\ y \end{bmatrix}$ $r_{0i} = \begin{bmatrix} x_{0i} \\ y_{0i} \end{bmatrix}$

$$\ddot{r}(t) = e^{-\alpha t}G(Ar - B); \quad t \geq t_n \quad (7)$$

In next step we have:

$$A = 2\sum_{i=1}^{n} e^{\alpha t_i} C_i^{-1} \quad \text{matrix } (2 \times 2) \quad (8)$$

$$B = 2\sum_{i=1}^{n} e^{\alpha t_i} C_i^{-1} r_{0i} \quad vector \quad (9)$$

where

$$C^{-1}=\begin{bmatrix}\frac{1}{\sigma_{11}^2} & 0\\ 0 & \frac{1}{\sigma_{22}^2}\end{bmatrix}=\begin{bmatrix}p_{xi} & 0\\ 0 & p_{yi}\end{bmatrix} \tag{10}$$

$$\ddot{x}(t)=-G(A_x x-B_x)e^{-\alpha t};\quad t\geq t_n \tag{11}$$

$$\ddot{y}(t)=-G(A_y y-B_y)e^{-\alpha t};\quad t\geq t_n \tag{12}$$

$$Ar=(A_x x, A_y y)\ and\ B=(B_x, B_y) \tag{13}$$

$$A_x=2\sum_{i=1}^{n}e^{\alpha(t_i-t_n)}p_{xi} \tag{14}$$

$$A_y=2\sum_{i=1}^{n}e^{\alpha(t_i-t_n)}p_{yi} \tag{15}$$

$$B_x=2\sum_{i=1}^{n}e^{\alpha(t_i-t_n)}p_{xi}\,x_{0i} \tag{16}$$

$$B_y=2\sum_{i=1}^{n}e^{\alpha(t_i-t_n)}p_{yi}\,x_{0i} \tag{17}$$

Final solution is:

$$\begin{cases} x(t)=\frac{B_x}{A_x}+a_1J_0\left(\frac{2}{\alpha}e^{-\frac{\alpha}{2}t}\sqrt{GA_x}\right)+a_2N_0\left(\frac{2}{\alpha}e^{-\frac{\alpha}{2}t}\sqrt{GA_x}\right)\\ y(t)=\frac{B_y}{A_y}+b_1J_0\left(\frac{2}{\alpha}e^{-\frac{\alpha}{2}t}\sqrt{GA_y}\right)+b_2N_0\left(\frac{2}{\alpha}e^{-\frac{\alpha}{2}t}\sqrt{GA_y}\right)\end{cases} \tag{18}$$

$$a_1=-\frac{\pi}{\sigma}\left[\left(x_n-\frac{B_x}{A_x}\right)\sqrt{GA_x}N_1\left(\frac{2}{\alpha}\sqrt{GA_x}\right)-x'_nN_0\left(\frac{2}{\alpha}\sqrt{GA_x}\right)\right] \tag{19}$$

$$a_2=-\frac{\pi}{\sigma}\left[\left(x_n-\frac{B_x}{A_x}\right)\sqrt{GA_x}J_1\left(\frac{2}{\alpha}\sqrt{GA_x}\right)-x'_nJ_0\left(\frac{2}{\alpha}\sqrt{GA_x}\right)\right] \tag{20}$$

$$b_1=-\frac{\pi}{\sigma}\left[\left(y_n-\frac{B_y}{A_y}\right)\sqrt{GA_y}N_1\left(\frac{2}{\alpha}\sqrt{GA_y}\right)-y'_nN_0\left(\frac{2}{\alpha}\sqrt{GA_y}\right)\right] \tag{21}$$

$$b_2=-\frac{\pi}{\sigma}\left[\left(y_n-\frac{B_y}{A_y}\right)\sqrt{GA_y}J_1\left(\frac{2}{\alpha}\sqrt{GA_y}\right)-y'_nJ_0\left(\frac{2}{\alpha}\sqrt{GA_y}\right)\right] \tag{22}$$

Our purpose is best estimation G and α from this equation

$$f(\alpha,G)=\sum_{i=1}^{n}\{[x(t_i)-x_{0i}]^2+[y(t_i)-y_{0i}]^2\}=minimum \tag{23}$$

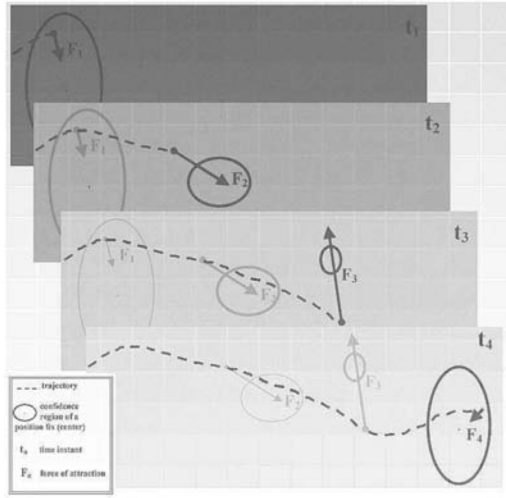

Figure 1. Visualization filter idea.

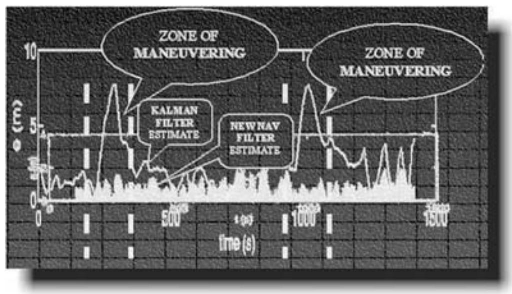

Figure 2. Alternative filter vs Kalman filter.

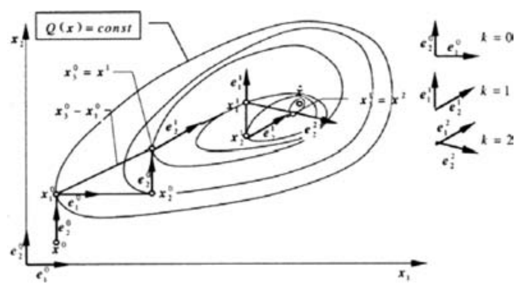

Figure 3. Powell Algorithm.

1 TODAY'S NAVIGATION SYSTEMS AND THE REQUIREMENTS PLACED ON THEM

Modern navigation are dominated by satellite systems and assist systems mainly including GPS – NAVSTAR GPS (called the Global Positioning System – Navigation Signal Timing and Ranging), in Europe EGNOS (called European Geostationary Navigation Overlay Service), which de facto is a service for GPS system and Russian GLONASS (called Global Navigation Satellite System, or in Russian Globalnaja Nawigacjonnaja Satelitarnaja Sistemma). Each of these systems offers similar functionality. Let focus on requirements that modern navigation systems should met with reference to existing systems.

Satellite system which can be considered for navigation must ensure:

– Accuracy; GPS does not meet expectations in terms of its accuracy, which is required in aviation - during landing approach. EGNOS is a system that uses GPS position and corrections from ground stations, offering greater level of accuracy than GPS and it is to be used in civil aviation starting 2008, but its accuracy is still between 2–3 meters, which is not fully satisfactory from Air Navigation or even Waterways Navigation (rivers) point of view. GLONASS is a system which is right now exchanging it's satellites constellation, but to date no civilian usage is possible.

– The ability of immediately alert users about system malfunction. A serious issue of GPS is lack of any communication containing information about its credibility (can we use it). Advanced users can view information from the various types of satellites, including healthy/un-healthy status but despite this, users can't obtain data on the state of the entire system. EGNOS in his assumption, as a GPS service was intended to correct its deficiencies, and so is about its ability to provide warnings about improper functioning of the system. EGNOS architecture based on the network of ground stations collecting errors which GPS generates can also determine the quality of the GPS information and instantly send notice to its three geostationary satellites, which will inform the end user about inability to use the EGNOS and in result GPS system.
– Continuity of service. GPS and so as the EGNOS are systems/services which do not meet the desired functionality even because of the fact that GPS is an U.S. property and in any threat situation it can be disabled. EGNOS is in the testing phase and its functionality is not yet complete
– Availability – is a factor expressed in percentage representing the time within the system may be used. The U.S. FAA (Federal Aviation Administration) organization demands availability for air-route navigation, while approaching and landing airports and during aerial surveillance no less than 99,999%. As previously found GPS is disqualified by lack of information about its credibility and availability at less than 99,999%, while the European EGNOS at the moment is in testing phase.

Unfortunately, none of these systems/services offer the level of accuracy of 1 meter without the use of differential techniques. Possible solution for this is usage and development of already existing filters or developing new ones or usage of mathematics and information based on assumptions which will allow individuals to increase the data accuracy regardless of expanding space installations (GPS III and Galileo).

2 EXISTING NAVIGATION FILTERS

Part of the problem is usually solved through a combination of two different types of information, observation and vehicle traffic by creating a model based on the basic rights of physics represented by different equations. Existing filters in navigation have been dominated by the Kalman filter in various forms. Kalman filter will be thoroughly discussed in chapter II. On the basis of experience and many publications related to navigation, especially in areas where the navigation is performed many maneuvers Kalman filter does not meet the requirements of accuracy (positional error has repeatedly been growing in the performance of maneuvers). The basis for conducting further research traffic is a working hypothesis that the existing model navigation filter does not meet the accuracy requirements for the movable object, it is assumed that the acquisition of improvement in this regard will be developed when submission to the new model navigation object memory.

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Chapter 13. Safety and reliability of technical systems

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13.1 Managing and predicting maritime and off-shore risk

R.B. Duffey
Atomic Energy of Canada Limited, Chalk River, Canada

J.W. Saull
International Federation of Airworthiness, East Grinstead, W. Sussex, United Kingdom

ABSTRACT: We wish to predict when an accident or tragedy will occur, and reduce the probability of its occurrence. Maritime accidents, just like all the other crashes and failures, are stochastic in their occurrence. They can seemingly occur as observed outcomes at any instant, without warning. They are due to a combination of human and technological system failures, working together in totally unexpected and/or undetected ways, occurring at some random moment. Massive show the cause is due to an unexpected combination or sequence of human, management, operational, design and training mistakes. Once we know what happened, we can fix the engineering or design failures, and try to obviate the human ones. We utilize reliability theory applied to humans, and show how the events rates and probability in shipping is related to other industries and events through the human involvement. We examine and apply the learning hypothesis to shipping losses and other events at sea, including example Case Studies stretching over some 200 years of: (a) merchant and fishing vessels; (b) oil spills and injuries in off-shore facilities; and (c) insurance claims, inspection rules and premiums. These include major losses and sinkings as well as the more everyday events and injuries. By using good practices and achieving a true learning environment, we can effectively defer the chance of an accident, but not indefinitely. Moreover, by watching our experience and monitoring our rate, understand and predict when we are climbing up the curve. Comparisons of the theory to all available human error data show a reasonable level of accord with the learning hypothesis. The results clearly demonstrate that the loss (human error) probability is dynamic, and may be predicted using the learning hypothesis. The future probability estimate is derivable from its unchanged prior value, based on learning, and thus the past frequency predicts the future probability. The implications for maritime activities is discussed and related to the latest work on managing risk, and the analysis of trends and safety indicators.

1 INTRODUCTION

1.1 *The Universal Learning Curve*

We have developed a general accident theory, so in this paper we emphasize and extract the relevant application to marine shipping. For any technological system with human involvement, like ships and shipping, the basic and sole assumption that we make is the "Learning Hypothesis" as a physical model for human behavior when coupled to a technology (Duffey & Saull 2002, 2008).

Simply and directly, we postulate that humans learn from their mistakes (outcomes) as experience is gained.

Although we make errors all the time, as we move from being novices to acquiring expertise, we should expect to reduce our errors, or at least not make the same ones. Thus, hopefully, we should descend a "Universal Learning Curve" (ULC) like that shown in Figure 1, where our rate of making mistakes decreases as we learn from experience and is exponential in form.

The past rate of learning determines our trajectory on the learning path and thus:

– how fast we can descend the curve;

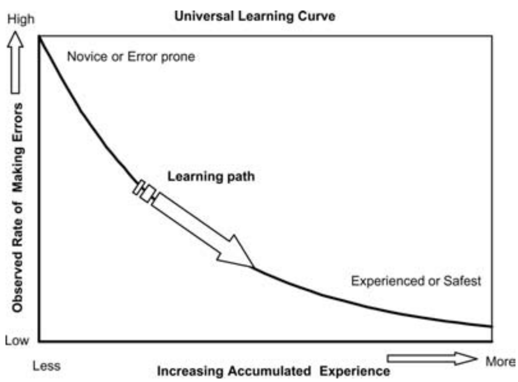

Figure 1. The Learning Hypothesis – as we learn we descend the curve.

– the rate at which errors occur determines where we are on the curve;
– changes in rate are due to our actions and feedback from learning from our mistakes;

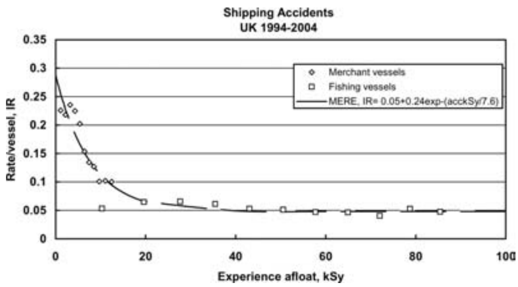

Figure 2. The learning curve for shipping accidents.

– no reduction in error or outcome rate could mean we have reached the lowest we are able to or that we have not sustained a learning environment; and
– an increase in rate signifies forgetting.

In our book that established the existence of the learning curve (Duffey & Saull 2002), we examined many case studies.

We highlight in this paper the data and information for marine events and their learning trends. We have also found data for oil spills at sea. Since spills are just another accident in a homo-technological system (HTS), namely a ship operated by people, it was interesting to show if the usual everyday marine accidents do exhibit learning. Marine accident outcomes include groundings, collisions, fires and all manner of mishaps. The most recent data we found were on the web in the Annual Report for 2004 of the UK Marine Accident Investigation Board (MAIB, for short, at www.maib.gov.uk). The MAIB responsibility is to examine reported accidents and incidents in detail. The MAIB broke down the accidents by type of ship, being the two broad categories of merchant ships that carry cargo, or fishing vessels that ply their trade in the treacherous waters off the UK islands.

In both types of ship, the number of accidents were given as the usual uninformative list of tabulations by year from 1994 to 2004, together with the total number of ships in that merchant or fishing vessel category, some 1000 and 10,000 vessels respectively. Instinctively we think of fishing as a more dangerous occupation, with manual net handling and deck-work sometimes in rough seas and storms, but surprisingly it turns out not to be the case.

We analyzed these accidents by simply replotting the data as the accident rate per vessel versus the thousands of accumulated shipping–years of experience, kSy. By adopting this measure for experience, not only can we plot the data for the two types on the same graph, we also see if we have a clear learning trend emerging. The result is shown by Figure 2, where the line or curve drawn shown is our usual theoretical MERE learning form.

We see immediately that, at least in the UK, the (outcome) accident rate is higher for merchant vessels than fishing boats, but also that learning is evident in the data that fit together on this one plot only if using experience afloat as a basis. The other observation is that the fishing vessels are at the minimum rate per vessel that the merchant vessels are just approaching. Perhaps the past few centuries of fishing experience has lead to that low rate so that, in fact, fishermen and fisherwomen are highly skilled at their craft. The lowest attained rate of ~ 0.05 accidents per vessel corresponds to an hourly rate if afloat all day and working all the time, of:

$$\sim 0.05/(365 \times 24) \sim 5.10^{-6} \text{ per hour} \qquad (1)$$

That is one accident per vessel every 175,000 hours, which is about the least achieved by any HTS or industry anywhere in the world, including the very safe ones like aircraft, nuclear and chemical industries of 100,000 to 200,000 hours. Even allowing for a duty factor afloat for the vessel or crew of 50% or so, or working at sea half the time, it is still of the same order. That last result is by itself simply amazing, and reflects the common factor of the human involvement in HTS. We now examine the learning hypothesis analysis again, but in some more detail.

2 THE RISK OF LOSING A SHIP

We can use data from shipping, as it is a technological system with human involvement that is observed and includes both outcomes and a measure of experience. Shipping losses are an historic data source, as insurers and mariners tracked sinkings; and the human element is the main cause of ship loss, rather than structural defects in the ships themselves.

A large dataset exists for ship losses in the USA, (Berman 1972). We analysed these extraordinary data files, which cover some 10,000 losses (outcomes) over an Observation Range of nearly 200 years from 1800 to 1971. We excluded Acts of War so as to avoid uncontrolled external influences and non–human errors. It is not known how many ships were afloat in total, only which ones sank, and thus became recorded outcomes.

A ship is built in a given year, sails for a while accumulating experience in ship-years afloat, Sy, and may or may not sink. From some 10,000 ships that were lost, we took a sample of the data only for ships over 500 tons, chosen so that we can compare with modern large commercial losses. In our sample of the data there were a total (N) of 510 losses of the ships.

From the entire set, we show one sample Observation Range in Table 1 for 1850 to 1860, selected arbitrarily from the entire data set. For these loss (outcome) data for 1850 to 1860, 17 ships were lost which had accumulated 265 shipping-years (accSy) of depth of experience before being lost. The losses, $N_i = 17$, are sparsely distributed and apparently random, as we might expect. The entire observation set of 1800 to 1971 can be formed by stacking these incremental observations ranges together for all the observed range and number of outcomes. But this again is only one subset of an array that could stretch over all recorded history, and all human experience – we just happen to not have all that data.

Table 1. Actual Ship Loss Data matrix: A sample outcome observation interval.

Year	1850	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	Sy	accSy	#Losses
1												0	0	0
2		1			1							4	4	2
3				1								3	7	1
4	1											4	11	1
5												0	11	0
6			1			1						12	23	2
7												0	23	0
8												0	23	0
9												0	23	0
10						1						10	33	1
11												0	33	0
12												0	33	0
13		1										13	46	1
14												0	46	0
15												0	46	0
16												0	46	0
17												0	46	0
18												0	46	0
19								1	2			57	103	3
20					1					1		40	143	2
21												0	143	0
22												0	143	0
23												0	143	0
24												0	143	0
25												0	143	0
26												0	143	0
27				1								27	170	1
28												0	170	0
29												0	170	0
30				1								30	200	1
31									1			31	231	1
32												0	231	0
33												0	231	0
34			1									34	265	1
35												0	265	0
36												0	265	0
37												0	265	0
38												0	265	0
39												0	265	0
40												0	265	0
Totals	1	2	2	3	2	2	0	1	3	1	0	265	265	17

The usual time history is given by the sum of the losses for any given year. Thus, for any year, y, there is a loss rate given by summing over all the experience range of losses for that particular observation, jth range year:

$$N_y = \sum_\varepsilon n_i(\varepsilon) \tag{2}$$

Meanwhile, for a given experience, ε, the total number of losses, N, is given by summing all the losses over the range at a particular experience, as:

$$n_i = \sum_y n_i(\varepsilon) \tag{3}$$

The sum of the number of Sy at any experience interval is simply given by adding up outcomes:

$$Sy(\varepsilon) = \sum_y (Sy\, n_i(\varepsilon)) \tag{4}$$

Hence, the accumulated experience in accSy's is as shown from adding the Sy's for all losses:

$$accSy = \sum_\varepsilon (Sy\, n_i(\varepsilon)) \tag{5}$$

Now we can calculate the outcomes for all the entire Observation Range for 1800–1971. We find the total losses of >500 tonnes are now of course as summed as all outcomes:

$$N_j = \sum_i n_i(\varepsilon) = 510 \tag{6}$$

and the accumulated experience is summed over the depth of experience:

$$accE = \varepsilon = \sum_j (n_i(\varepsilon)\, Sy) = 11{,}706 \text{ accSy} \tag{7}$$

So we have confirmed the postulate that we may represent outcomes by a distribution of errors as a function of experience, and where all outcomes are equally likely.

On average, therefore, ships spent an average of 11,706/510 = 23 years afloat before sinking.

3 SHIPPING LOSS DISTRIBUTION FUNCTIONS

If the losses were truly random in time, then on average the chance is equal that a ship would be lost either side

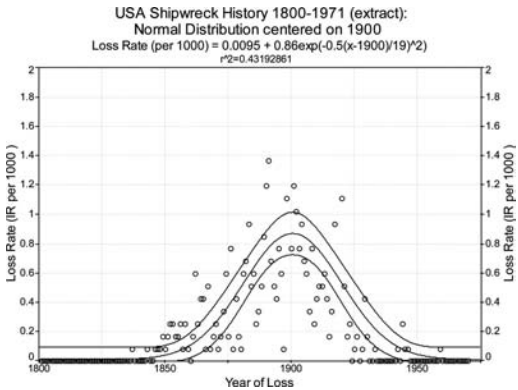

Figure 3. Loss rate fitted with a normal distribution.

of the middle of the Observation Range, or centered on the date:

$$1800 + (1971 - 1800)/2 = 1885, \quad (8)$$

and the loss rate distribution should follow a binomial (normal) distribution. The actual distribution of the loss rate data does just that, and data for *the entire Observation Range* is shown in Figure 3, including the 95% confidence bounds.

The fitted loss rate distribution actually centers on 1900, and is given by:

$$\text{IR(per kSy)}=0.0095+0.86 \exp 0.5((\text{Y}-1900)/19)^2 \quad (9)$$

where 1 kSy = 1000 Sy.

Since the data have a normal distribution, the outcomes are indeed randomly distributed throughout the entire 1800–1971 Range. The standard deviation of 19 Sy and the 95% confidence limits do actually encompass the predicted date of 1885, within the errors of the data sampling and fitting. The most probable loss (outcome) rate is ~0.86 per 1000 Sy, which is close to that observed today (~1 per kSy) by major loss insurers. The most probable rate has not changed for over 200 years, and the range at 95% confidence is 0.7 – 1 per kSy.

As to the systematic effects of ship-age, it has been characteristic practice to have higher insurance for older ships, implying there risk of loss is greater, and that the outcomes (vessel sinkings, groundings, collisions, etc.) are not random. Older vessels are then *classified* as higher or greater risk. The actual data are shown in Figure 4 for losses in excess of 500 tonnes for two outcome sets spread over two centuries. Clearly, there is little difference between them; and the outcomes are almost normally distributed over the life of the ships with about 40–50 years maximum. The maximum loss fraction peak is at about 15–20 years of ship-life.

Now in terms of the influence of accumulated experience, we may plot the loss rate per ship-year versus the accumulated experience in accSy as shown in Figure 5.

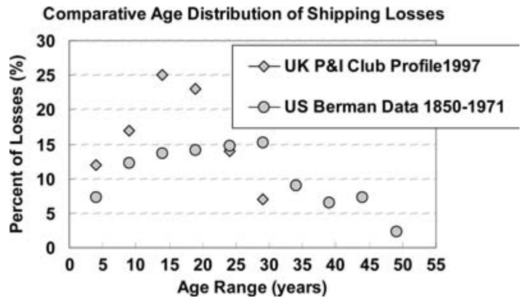

Figure 4. Comparison of shop losses as a function of age.

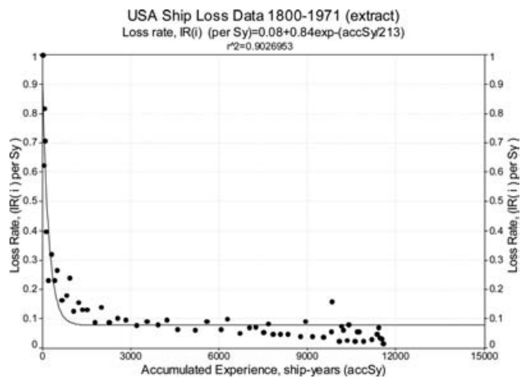

Figure 5. The learning curve for shipping.

The loss rate as a function of the accumulated experience in accSy is then given by a best-fit line of the exponential form derived for the distribution of the total number of microstates:

$$A \approx A_m + A_o e^{-\varepsilon/k} \quad (10)$$

or

$$\text{A (losses per Sy)} = 0.08+0.84 \exp-(\text{accSy}/213) \quad (11)$$

This result implies an initial loss rate many times higher than the equilibrium value, and a minimum rate of ~0.08 per Sy for those that sank. This is of course telling us that on average the ships that sank lasted for a depth of experience afloat of about (1/0.08) or ~13 Sy, starting off lasting some 10 times less (~1 Sy). It does *not* tell us how long the average ship lasted, including those that were not lost, and indeed this is irrelevant for the moment. We just want to predict the relation between sinking rates and ship lifetimes. On an accumulated rate basis the predicted loss rate is now ~1 per 1000 Sy, illustrating the importance of the data sample size Observation Range for apparently random events.

Thus we have confirmed the postulates that:

– a systematic learning curve exists superimposed on the apparently random losses which we observe as outcomes;
– a relevant measure for accumulated experience and depth of experience can be found (in this case years-afloat); and

– a minimum asymptotic rate does exist, and is derivable from the learning curve.

4 OIL SPILLS AT SEA: TRACKING LEARNING TRENDS

We have provided an initial analysis of importance to the safety and environmental impact of the oil storage and transportation industry, using publically available USA data on oil spills, shipping losses and pipeline accidents, not having access to the oil and gas industry's privately held spill database (Duffey et al 2004).

Spills and accidents can arise in many ways e.g.:

- while filling;
- in storage;
- during transport;
- at process and transfer facilities; plus
- failure of vessels and pipelines.

We would expect significant human involvement in the design, management and operation of all these technological activities, in the piping, pumping, tanks, valves and operations. For handling and storage of (petro) chemicals, the risk of a spill or a loss is also dependent on the human error rate in the transport or storage mode and the accumulated experience with the transport or storage system.

The US Coast Guard database for oil spills was the most comprehensive we found, but is given in the usual annual format of tables. For shipping spills, in the oil spill database for the observation interval from 1973 to 2000, we found information for 231,000 spill events for the USA, while transporting a total of oil of nearly 68 Btoe, of which 8,700 events were spills of more than 1000 gallons. Assuming there is pressure from the EPA, industry, owners and others to reduce spills rates, then there is a nominally large HTS learning opportunity. We can easily extract the number of spills from such tables and transform it to an experience basis (Duffey & Saull 2008), replacing the list of numbers of outcomes on a purely calendar year reporting basis. The measure for the accumulated experience we took was the total amount of oil being shipped in and out of the USA, which is not given in or by the USGS raw datatables. The US DOE track the oil consumption information and where it comes from for purely energy analysis purposes. The datatables for crude oil and petroleum products were given in the DOE Petroleum Overview, for 1949–2001, and the details of the calculations we have given elsewhere (Duffey & Saull 2008 in Chapter 8).

The summary result is shown in Figure 6, and follow a clear learning curve, which is also shown fitted to the data.

5 INSURING MODERN LOSSES: THE MOST PROBABLE AND MINIMUM ERROR RATE

Now having established the learning curves and loss rates from historical data, we have also confirmed the

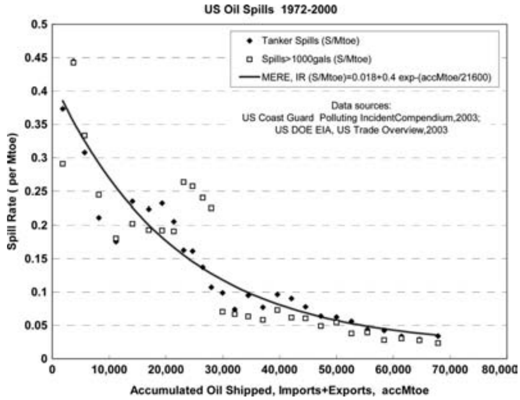

Figure 6. The oil spill learning curve.

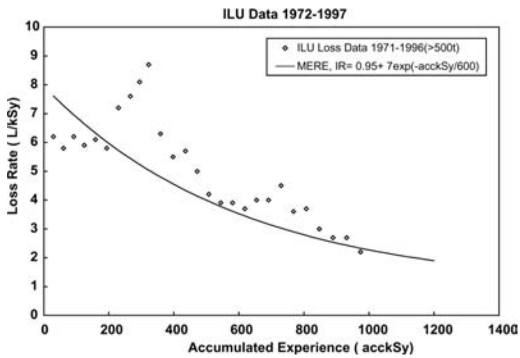

Figure 7. Modern Ship Losses.

results by testing the analysis against other data for modern fleets, where losses for all ships over 500 tonnes were tracked. These include data for modern vessels (Institute of London Underwriters 1988) for losses greater than 500 tonnes for 1972–1998, and for the latest (UK Protection and Indemnity Mutual Insurance Club 2000) Major Claims data from 1976–1999.

In these modern datasets, we also know how many ships were afloat, but the years afloat for each ship were not known (the converse to the Berman dataset). The Observation Ranges were smaller (~25 years), but covered the world-wide total losses which are comparable in number.

The data is shown in Figure 7, where we have the loss rate for the ILU dataset for 1972–1998 worldwide is given by, for some 30,000 ships afloat in any Sy, accumulating nearly a million Sy in total, and some 3,000 outcomes (losses) over the 26 year Range:

$$A \approx A_m + A_o\, e^{-\varepsilon/k} \quad (12)$$

or,

$$A \text{ (losses per kSy)} = 0.95 + 7 \exp -(\text{acckSy}/600) \quad (13)$$

This result shows an asymptotic or minimum loss rate of ~0.95 per kS/y for losses > 500 tonnes in

1972–1998 (despite observing nearly 2 /kSy now). We have a similar estimate for the Major Loss data, that is greatest in terms of financial cost, which shows a loss rate of ∼1 /kSy (Pomeroy 2001), which is a value consistent with the above analyses.

This lowest predicted minimum rate of ∼0.95 /kSy is consistent with the most probable rate independently derived from the data for losses only (i.e., 0.86 ± 0.1 per kSy) for 1800–1971. Since the two datasets do not overlap, meeting in 1970, and one is for losses only in the USA and one is for all ships afloat world-wide, we have shown that:

– the minimum error rate predicted for modern ships is close or equivalent to the most probable loss rate for the last 200 years, which if correct also confirms the postulate of the most probable distribution used in deriving the microstates distribution formula;
– the distribution of microstates (manifested as an outcome rate) is apparently independent of technology or date, and is due to the dominant contribution of the human element; and
– the learning curve approach is consistent with the statistical distribution of error states.

6 LEARNING RATES AND EXPERIENCE INTERVALS: THE UNIVERSAL LEARNING CURVE

The two datasets we have studied are at first sight quite distinct, even though both are observed and recorded only for losses greater than 500 tonnes. The observational intervals, the accumulated experience and the number of outcomes are drastically different.

One set (set A) is from 1800 to 1971, and gives a distribution of microstates for only losses for the USA with an experience base of about 10 kSy. The other (set B) extends that set A from 1971 to 1996, but is for the distribution of microstates for losses of all ships world-wide with an experience base of nearly 1000 kSy. Therefore, the depth of experience is quite different. The accumulated experience, $\Sigma n_i \varepsilon_i$, is then quite different for each set, by the same factor of 100. Above, we have shown the learning curve rate constants are also different, being ∼200 Sy for set A, and ∼600 kSy for set B, which is a factor of ∼3000.

So, for these Ranges, the predicted "learning rate ratio" between experience intervals for the losses only in the USA and for the whole world fleet afloat is:

$$\beta_A \varepsilon_A / \beta_B \varepsilon_B \sim 30 \qquad (14)$$

Recall again that dataset A was for all ships afloat world-wide, while dataset B was just for those that sank in the USA. The ratio above suggests that the experience interval ratio of the USA losses to the world fleet afloat is $(\varepsilon_A/\varepsilon_B) \sim 1/30$ (i.e., 3%), particularly if $\beta_A \sim \beta_B$.

To test that ratio prediction, recall also that for the ILU data in ∼25 years we had 3000 losses of ∼30,000 ships afloat at any time. That is a loss rate percentage for the whole fleet of order $(3000/25) \times (100/30000) = 0.4\%$ world-wide. But only a fraction of the world fleet actually sailed and sank near the USA. To determine that fraction, we sought another random sample Observation Range of losses and found an excellent one in the "Atlas of Ship Wrecks and Treasure" (Pickford 1994). Now the Atlas lists about 184 ships sunk off the East, West and Caribbean coasts of the USA between 1540 and 1956 out of a listed sample world-wide of 1400 losses. That is only a fraction of $(184/1400) \times 100 = 13\%$ of the world's ship losses were in the waters off the USA. We assume that fraction holds for the much later ILU dataset, which was for all ships >500 tons.

So if just 13% of the ships world-wide sank off the coasts of USA, and only 0.4% of the fleet sank in total around the world, we would have 0.4%/0.13 ∼3% as the experience interval ratio of only the USA losses to the total world total fleet afloat. Therefore, we have near perfect agreement versus the predicted ratio from the theory of 3% (or a factor of 30).

Given the uncertainties in the calculations, and the vast differences in the datasets, this degree of agreement with the prediction seems almost seems fortuitous and better than might be expected. But the comparison does confirm the general approach and indicate how to compare datasets that possess very different experience bases.

Let us try to test another prediction: if the theory, postulates and analogies are correct the two datasets should both follow the trend predicted by the ULC. We can directly compare the two learning rates for set (A) and set (B) with their very different experience bases by using the non-dimensional formulation of the ULC for correlating data, i.e.,

$$E^* = \exp\text{-}KN^* \qquad (15)$$

We correct the learning rate constant for the USA losses only for the ratio of ∼30 derived above. The actual learning curves give all the needed estimates from the data for A_0 and A_m, which is sufficient to calculate E* for each microstate. We also have the total experience, ε, necessary to derive the non-dimensional value of N*. Strictly speaking N* should be taken as the ratio of experience, ε, to the experience, ε_M, needed or observed to reach the minimum error rate, λ_m, or at least the maximum experience already achieved with the system.

The comparisons of the ULCs suggested by the theory are shown in Figure 8. We have also shown the best-fit correlation to world data, i.e., with K ∼3,

$$E^* = \exp\text{-}3N^* \qquad (16)$$

The value of K ∼ 3 was derived from analyzing vast datasets covering millions of error states that included amongst other things (Duffey & Saull 2002, see Figure 1.7 in Chapter 1): USA data for deaths in recreational boating 1960–1998; automobile crashes 1966–1998; railway accidents 1975–1999; coal mining for 1938–1998; plus South African gold and coal mining injuries 1969-1999; UK cardiac surgeries 1984–1999; US oil spills 1969–2001; French latent error data 1998–1999;

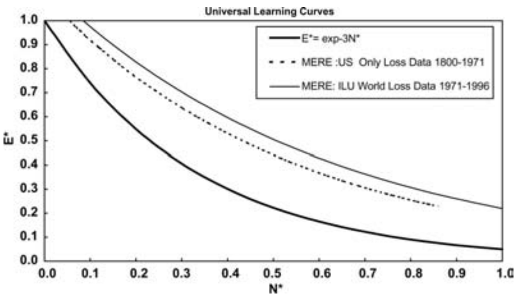

Figure 8. Comparison of trends with the ULC.

US commercial aircraft near misses 1987–1997; and also world pulmonary deaths for 1840–1970.

The two other lines, for the US (Berman) losses only and ILU world shipping datasets, are given by the MERE predictions calculated from:

$$E^* = \exp\text{-}KN^* = \exp - ((1 - A/A_m)/(1\text{-}A_0/A_m)) \quad (17)$$

whence

$$A = A_m + (A_o - A_m)e^{-\varepsilon/k} \quad (18)$$

and the values for k, A_m and A_0 are derived directly from those given by the theory and the data. The 213 Sy in the exponent is adjusted for the observational experience interval ratio and becomes $k = 213 \times 30 = 6390$ Sy = 6.4 kSy.

Hence, the only adjustment we have made or needed was to correct the learning rate constant for the differing depths of experience. We justify the factor of ∼30 simply to bring the experience interval for the losses in the US only data consistently into line with the world experience interval. The remaining differences between the predictions are well within the overall data scatter.

This method thus allows apparently quite disparate datasets to be renormalized and intercompared. The universal learning trends are essentially the same, and we have validated the overall theoretically predicted trend.

Thus, we have succeeded in not only getting the two very different datasets on the same plot, but in obtaining agreement with the world trend derived from a wide range of totally independent data. Using the non-dimensional variables derived from theory, we have shown that the trends are correct. This agreement is despite the numerical changes being very large, by a factor of ∼100 in the learning rate ratio and a factor of 1000 in the accumulated experience, as we have discussed above.

7 PRACTICAL APPLICATION: PREDICTING LOSSES AND MANAGING RISK

Data are essential to measuring performance. Note that the shipping error/loss rate is not affected by the massive technology changes in shipping (from sail to steam, from wood to steel) occurring over the last two hundred years. Losses are dominated by human (crew) performance. The overall loss rate (∼ one per thousand ship years afloat) enables the prediction of loss probability, which affects both insurance costs and classification. In addition, the learning curve provides the probability of operational error, which is a function of the shipping maneuver or course transient. In principle, the analysis then provides the likelihood of collision, grounding or near misses.

As for other industries and technologies, it would be useful and necessary to have further data maritime continuously collected on actual events, and to develop nautical performance indicators, that can be updated continually for loss and risk assessment purposes. Such an activity is underway for offshore oil and gas fields in the North Sea for both mobile and fixed facilities (Duffey & Skjerve 2008). Such objective measures and indicators enable the presence or absence of learning trends to be discerned, enhancing the management of risk exposure and prediction of losses, and hence would help guide improvements in maritime training, safety and loss control.

8 CONCLUSIONS

We have described a general and consistent theoretical model, however simplified it may be, which describes the rate of outcomes (losses) based on the classic concept of learning from experience. The approach is quantifiable and testable versus the existing data and potentially able to make predictions. We reconcile the apparently random occurrence of outcomes (accidents and errors) with the observed systematic trend from having a learning environment. We can now explain and predict outcomes, like ship losses, collisions and sinkings, and their apparently random occurrences because the human element component is persistent and large.

We infer that *risk reduction (learning) is proportional to the rate of errors being made, which is derived from the total number of distributions of errors.* We have validated the new theory, and in this paper summarize the use of marine loss and oil spill data as a working example. We analyzed shipping losses over the last two hundred years, which are an example of one such system and a rich data source because insurers and mariners tracked sinkings. Human error is and was the pervasive and main cause of ship loss, rather than structural defects in the ships themselves. The validation results support the basic postulates, and confirm the macroscopic ULC behavior observed for technological systems.

Our new theory offers the prediction and the promise of determining and quantifying the influence of management, regulatory, liability, insurance, legal and other decisions.

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13.2 Transportation system architecture for intelligent management

J. Szpytko
AGH University of Science and Technology, Krakow, Poland

ABSTRACT: The paper is focusing on transportation system architecture for intelligent management, especially in sea transport and transportation technology. Moreover control models of large-scale distributed enterprises systems and transport active knowledge base management model have been presented.

1 INTRODUCTION

Today the transportation organization systems, especially see transportation, are much complex and must be more safety and robustness for any internal and external disturbances resistance for any errors and human mistakes. Criticality factors, which have influence on each dedicated activity, are including: safety, technology, exploitation (operation and maintenance), revenues, availability, reliability, maintainability, and costs.

The market globalization place new challenges in management of peculiar man activities in particular in transportation activities. It is growing requirement on so-called intelligent transportation technology and transport service ITS type (*Intelligent Transport Services*), as well as dynamical type management of transportation devices DTM type (*Dynamic Traffic Management*), both on large distances and at integrated automated transportation worldwide industry (manufacture). Transport industry today is a large-scale distributed system.

Market globalization and an increase in customer demands have forced companies to produce more complex and individualized products in a shorter lead-time [Le Duigou et al, 2009]. The increasing needs for flexibility, reactivity and efficiency result in a growing complexity of any systems including transport industry and other manufacturing, and a necessity of integration of their control based on numerous and highly versatile dynamic data [Blanc et al, 2008]. To solve this paradox (refocus on the primary business and need of multiple specific skills), companies have adapted by regrouping in order to pool their mutual skills. When this is done over a short period and on a specific project, it is called *virtual enterprise*, and *extended enterprise* when it is done over a longer period. Companies is not structured enough to enable efficient cooperation.

Knowledge is now a major driving force for organizational change and wealth creation, and effective knowledge management is an increasingly important source of competitive advantage and a key to the success of modern organizations [Irma & Rajiv, 2001; Malhotra, 2002; Savvas & Bassiliades, 2009]. The core technological areas for the success of next generation manufacturing related to information and communication technologies have been expressed in paper [Nof et al, 2008]. As a result, companies are now implementing knowledge management processes and its supporting technologies. Knowledge management systems (KMS) are a class of intelligent systems (IS) developed to support and enhance the organizational processes of knowledge creation, storage/retrieval, transfer and application [Alavi, & Leidner, 2001; Chang et al, 2005]. Recent advances in information and communication technologies have allowed both transportation and manufacturing systems to move from highly data-driven environments to a more cooperative information/knowledge-driven environment [Panetto & Molina, 2008]. For many years, software has been developed to pool all this information. From the EDM (Electronic Document Management) in the 1980s to the PDM (Product Data Management) and the PLM (Product Life Cycle Management) in the late 1990s, the companies and particularly the contractors understand the benefit of such software. Today to generate a common language for communication between people [Studer et al, 1998] or interoperability between systems [Uschold, 1996], more and more researcher are looking for ontologies types ranging in their formality, structure and intended use. The term ontology comes from philosophy and signifies a systematic account of existence [Gruber, 1993] and defines a common vocabulary for researchers who need to share information in a domain [Noy & McGuinness, 2001]. Building Information Modeling (BIM) [Penttila, 2006; Succar, 2009] of any today transportation and manufacturing systems is a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the system life-cycle phases.

Due to the geographical and institutional separation between the different systems involved in the product (system) lifecycle, it is today difficult to query, to exchange and to maintain consistency of product information inside the extended enterprise. By analogy with the definition of *interoperability* as the ability of two or more systems to exchange information and have the meaning of that information accurately and automatically interpreted by the receiving system [Wegner, 1996; Panetto, 2007], the *product oriented interoperability* as the ability of different enterprise systems to manage, exchange and share product information in a complete transparency to the user and utilize essential human labour only has been introduced [Baina et al, 2009].

Transport modes (road, rail, water, air, manufacture) integration and interoperability in transportation systems is a key concept to face the challenges of new transportation environment. The integration and interoperability concepts need undertake under the consideration the following problems: miscellaneous transport enterprise integration and interoperability, transport system as distributed locally and globally organization that can be readily reconfigured, methodology for system synthesis and simulation for all transportation operations, possible transportation activities and devices monitor and control with use proper model-based methodology, possible heterogeneous environments of transportation activities, open and dynamic structure of transport system, internal and external cooperation between transport modes and devices, technologies that can convert information into knowledge for effective decision making, enhanced human - machine interfaces based on integration of humans with software and hardware involved in transportation activities with use in-build intelligence, continuous educational and training methodology that would enable the rapid assimilation of existing and future knowledge and practice, transportation system safety and availability keeping with use preventive maintenance methodology, processes that minimize energy consumption resulting new innovative-based solutions in transportation system design and exploitation.

The paper is focusing on transportation system architecture for intelligent management, especially in sea transport and transportation technology.

2 CONTROL MODELS OF LARGE-SCALE DISTRIBUTED SYSTEMS

The main target of any complex system is a transport execution system (TES). The TES aim is controlling the transport system: what and when to replace, how and when to use the available resources, which and when to launch orders. The proposal of execution system based on manufacturing execution system MES using the holonic manufacturing system (HMS) concepts is presented in publication [Blanc et al, 2008]. An HMS is a highly decentralized manufacturing system concept, consisting of autonomous and cooperating agents called holons (proposed by Koestler in 1969) that respects some flexible control rules forming a holarchy. Holonic architectures are based on a typology of manufacturing elements, where each one corresponding to a type of holons:

- products, product holons own reference models of products, for manufacturing execution and quality control,
- resources, resources holons are components used as bricks with local intelligent decision-making system embedded and based on characteristics of the tasks they perform a specialization of resource holons; resource holons corresponds to the physical devices of the manufacturing system (machine, workforce, transport device, etc.); they allocate, organize and control the production resources; each physical device of the manufacturing system is a part of a resource holon,
- orders, order holons are related to product demand in time, manufacturing task and product item; order holons correspond to a task in the manufacturing system; they control the logistics aspects of the production as much as the negotiations with other order holons or with resource holons in order for the task to which it corresponds to be performed correctly and on time.

In paper [Zachman, 1987] author propose two-dimensional classification complex system model based around the six basic communication interrogatives: what (based on data), how (based on function), where (based on locations), who (based on people and devices), when (expressed via time), and why (expressed on motivation base), intersecting six distinct model types which relate to stakeholder groups: visionary, owner, designer, builder, implementer and worker, to give a holistic view of the enterprise. The proposed view of the enterprise can be extended on product – driven control concept.

Product-driven control is a way to exchange the hierarchical integrated vision of plant-wide control for a more interoperable/intelligent one [Morel et al, 2007; Pannequin et al, 2009] by dealing with products whose information content is permanently bound to their material content and which are able to influence decisions made about them [McFarlane et al, 2003]. This approach is applicable at the supply chain decision systems, such as MRP2 (Manufacturing Resource Planning II) [Vollmann et al, 1997] with newer distributed control approaches. Product-driven control may enable manufacturing companies to meet business demands more quickly and effectively. But a key point in making this concept acceptable by industry is to provide benchmarking environments in order to compare and analyze their efficiency on emulated large-scale industry-led case studies with regard to current technologies and approaches.

Over the last decade, agent technology has shown great potential for solving problems in large-scale distributed systems. By definition, in multi-agent systems, several agents work together and share their knowledge for achieving certain manufacturing objectives. One of the important features of these systems is that they facilitate integration and automation and provide benefits with several advantages, especially to the distributed manufacturing systems [Oztemel & Tekez, 2009]. However, the integration and coordination, as well as communication of these agents still need more attention and research.

The reason for the growing success of multi-agent technology in this area is that the inherent distribution allows for a natural decomposition of the system into multiple agents that interact with each other to achieve a desired global goal [Hernandez et al, 2002]. The multi-agent technology can significantly enhance the design and analysis of problem domains under following three conditions [Adler & Blue, 2002]: the problem domain is geographically distributed, the sub-systems exist in a dynamic environment, sub-systems need to interact with each other more flexibly.

A dynamic and demanding environment characterizes the modern society. Intelligent products normally need to provide services that require decision-making and goal-oriented behavior. This human as an intelligent being mirrors its product's, reflects corresponding reality while delegating all decision making to the intelligent agent Intelligent systems (IS) can be defined as systems which process input signals to actuate an output action, the form of which will depend on rules based on previous experiences where the system learned which actions best let it reach its objectives [Barton & Thomas, 2009]. Artificially intelligent systems (AIS) incorporate additional functionality, often through intermediary agents, to simulate, decide and control the output signal or action. AIS must be interoperable with other components, such as common sense knowledge bases, in order to create larger, broader and more capable AI systems. New technologies such as RFID (Radio Frequency Identification), Auto-ID (Identification), UPnP (Universal Plug – and – Play) enable identification and information embedding on the product itself. Moreover, technologies related to multi-agent systems make it possible to involve the product in decision making protocols at the shop floor level.

The concept of dynamic hierarchical control system architecture is presented in paper [Brennan et al, 1997]. This concept organizes multiple agents dynamically based on task decomposition of the system. To achieve dynamic organization, a number of heterogeneous agents are dynamically grouped into virtual clusters as needed.

Increasing flexibility and the ability of the transportation systems deal with the uncertainty in a dynamic environment. A stationary type agent executes only on the system where it begins execution, and the code of stationary agents, including control algorithms and provided services, cannot be changed during execution. The above inconvenience can be replaced by the introducing to the transportation system mobile type agents. Mobile type agent has the unique ability to replace itself from one system in a network to another and to move to a system that contains an object with which the agent wants to interact and then to take advantage of being in the same host or network as the object. Since mobile agents can be generated dynamically during the execution, new software components (control algorithms or operations) can be deployed as mobile agents and be executed on any sub-systems in a network [Hernandez et al, 2002]. The strength of mobile agents has great value for the application in traffic management systems. A traffic information system is usually distributed and the integration of data from distributed detection stations takes a long time. If a mobile agent can migrate to detection stations near incident scene and process data locally, it will significantly reduce the delay of incident response. Mobile type agent technology has been discussed by several researches [for example: Lange and Oshima, 1999; Gray et al., 2002; Szpytko, 2004; Szpytko & Kocerba, 2008]. The mobile type agents for example have strong influence on work in heterogeneous environments and disconnected operation supporting, network load reducing and network latency overcoming, as well as are able to deploy new decision making algorithms dynamically.

3 TRANSPORT ACTIVE KNOWLEDGE BASE MANAGEMENT MODEL

The transport system is mostly composed from three categories of agents: device, man-operator (device, service/maintenance, general coordinator/management), surrounding. Between each agent exist specified relation/controls, for example between operator and device attributes' exists several correlations: perception – information visualization, knowledge – monitoring, skills – operation realization ability, decision making ability – corrective auto-activity, reaction on external stimulus – safety device and strength.

Each agent is an object of supply and controls (IN). Man-operators are equipment with modules of knowledge and skills (with use of own in-build sensors), which make possible auto-correction of done controls as the results of undertaken activities [Smalko & Szpytko, 2008]. Moreover the device, depending on automation level, may be equipped in auto-corrective module (self-acting). The output products (OU) of activities undertaken by individual agents are shaping for decision-making needs in quality module.

The architecture of proposed integrated distributed agent-based transportation system has multiple levels as shown in figure 1: real enterprise based on nature type resources (RE), virtual enterprise (VE), supervisor (SU).

Legend:
ACC – Agent Communication Channel
ADB – Agent Data Base
ADS – activities detection subsystems
ADS-N – activity detection subsystem, N-th type, (ST – stationary, MO – mobile type)
AES-M – activity execution subsystem M-th type, on particular geographical scope (ST – stationary, MO – mobile type)

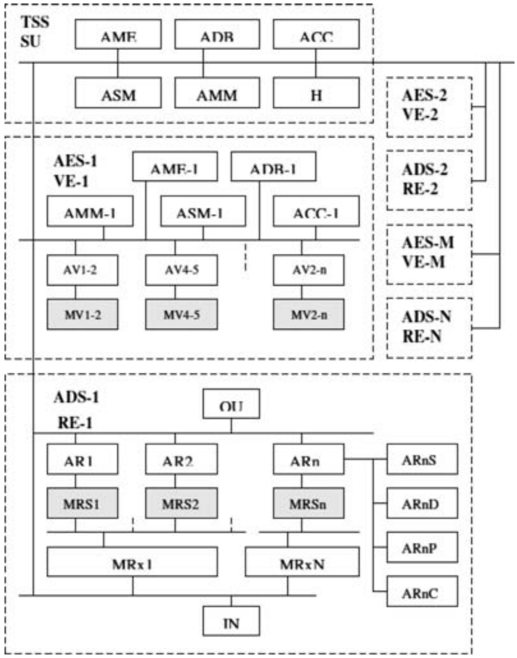

Figure 1. Integrated distributed agent-based dynamic type transportation management system (TMS).

AME – Agent Management/ Execution Engine
AMM – Agent Maintenance Manager
ASM – Agent Security Manager
Ax – activity supported by the x type agent, x = {R – real, V – virtual}
Axny – n-th activity of x-th type agent is composed from the following possible basic activities: y = {S – storage, D – displacement, P – processing, C – control}; to control one at least activity of S or D or P type must occur
ID – identification agent cod ID = 1….n
ID n.m – identification activity code n.m means that the activity is composed base on the two different activities with ID = n and ID = m
INn – input, which is composed by the following suppliers: ENIN-n – energy, KN-IN-n – knowledge and experience, IFIN-n – information/data, FI-IN-n – finance; IN = {ENIN,KN-IN, IF-IN, FI-IN}
MR – agent real, types: ST – stationary, MO – mobile type
MRS – senor type agent of any operation parameters of real world
MRx – agent x type, x = {M – devices, E – environment, H – human}
MV – virtual type agent
OUn input, which is composed by the following suppliers: ENOU-n – energy, KN-OU-n – knowledge and experience, IFn – information/data, FI-OU-n- finance; OU = {ENOU, KN-OU, IF-OU, FI-OU}
RE – resources (devices, environment, human, sensors/detectors, energy, knowledge and experience, information, finance)
TSS – transport supervisory subsystem (ST – stationary type), system supervisor (SU)
VE – virtual enterprise subsystem (ST – stationary, MO – mobile type)

The control architecture of transport management system (TMS) has three layers: real devices operating in real enterprise type agent (lower layer level A), e-devices operating in virtual enterprise type agent (middle layer level B, electronic type platform), supervisor agent (highest layer C, with human support). Under certain scenarios, a number of various agents on A-th level are dynamically grouped and interact with each other to perform a given task. The performed task is based on possible defined activities: S -storage, D -displacement, P -processing, C -control. The activity execution subsystem (AES) agent coordinates agents operating on A-th level in a sub-network. The transport supervisory subsystem TSS type agent operation on C-th level can assign tasks to either AES agents on B-th level or to the lowest agents directly on A-th level. The communication between agents on all levels and inside each level is based on agent communication language and message exchange interaction protocols.

At the agent-level, the conformance includes agent communication language (ACL), message exchange interaction protocols, communicative acts, and content language representations. At the platform-level, Mobile-C provides an agent management system to manage the life cycle of the agents, agent communication channel to allow agent communication over the network, and directory facilitator to serve as yellow page services.

The lowest level is composed of various activity detection subsystems (ADS), which enclose various MR type agents stationary and/or mobile types (e.g. transport devices) responding for particular activities AR types (e.g.: S – storage, D – displacement, P – processing, C – control types). Sensors (MRS) detect real agents activity parameters that can be a subject of monitoring for decision-making process. For example the useful information for the operation management is travel time, transport device speed, incident verification, and traffic volume and for the transport device technical state assessment – selected operation parameters of agents. MR type agents can dynamically group (taken under consideration overlooked necessary activities type) into any cluster according to the task assigned by the system supervisor. Integrating stationary type agents with mobile agent technology is leading to multi-agent subsystems for distributed transport management system. Mobile agents (operation base on dynamic adaptive type algorithm) enhance the ability to deal with the uncertainty in a dynamic environment and helps to achieve the cooperation between distributed agents response for various activities.

The second level so-called activity execution subsystem (AES) agent, either stationary and/or mobile types, is a coordinator of lower level agents ADS type in a sub-network. All of the lower level agents register themselves and their services with an AES agent. The AES type agent has the knowledge of geographical distribution of lower level agents and their capabilities. The selected tasks of activity execution subsystem are: decompose tasks assigned by the AES to sub-tasks, multi-operation with other AES agents activities to solve inter-network problems (interoperability), serve as agent name server and maintain the available services of agents in a sub-network, dynamically group lower level agents activities into a cluster according to the task assigned, coordinate agents activities to accomplish the task resulting of planning, scheduling and tracking, integrate the information flow from lower level agents and report to the supervisor SU agent.

The transport supervisory subsystem TSS type agent (stationary) is designed to perform following tasks: generate transportation tasks dynamically and assign these tasks to lower level agents, analyze the information from lower level agents and generate reports or control proposals, create both stationary and mobile type agents and dispatch them to various activities undertaken via on purpose established companies, interface the transport management system (TMS) composed via both virtual and real enterprises to accept human commands. The structure of transport supervisory subsystem TSS type agent is composed on: Agent Communication Channel (ACC, to route messages between local and remote agents and realizes messages using an agent communication language), Agent Security Manager (ASM, to maintain security policies for e-platform and whole transport infrastructure), Agent Maintenance Manager (AMM, to provide preventive type maintenance base on agents' condition monitoring), Agent Management/ Execution Engine (AME, to manage the life cycle of agents and to serve the execution environment for the mobile agents), Agent Data Base (ADB, to store the data/ information and knowledge in electronic format) and human operator (H, to make the critical type decision). The same counterparts we can find in the activity execution subsystem (AES) agents.

4 FINAL REMARKS

The presented transport management system (TMS) is dedicated not only to manage the defined transportation target base on own distributed resources based on dedicated agents, but also to manage the life-cycle of the agents from operation and maintenance point of view.

Using the described system is possible to conduct the transportation system optimization taken under consideration the safety, availability, reliability, finance, time and others important aspects.

Proposed transport active knowledge agent base management model is possible to use to different transport systems (e.g. see, air, road, rail, manufacture) separately, but also in dedicated clusters.

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13.3
Risk analysis and human factor in prevention of CRG casualties

L. Kobyliński
Foundation for Safety of Navigation and Environment Protection, Iława, Poland

ABSTRACT: CRG casualties create one of the major type casualties in shipping. Prevention of CRG casualties is an important issue, especially because of the number of CRG casualties has increased almost twice during recent years. For the great majority of all CRG casualties human factor responsible, and the increasing number of these casualties might be attributed to poorer qualifications of ship masters who have not enough experience in handling very large ships put into operation presently. Risk analysis is a modern method for assessment of safety level of technical systems. This tool may be the used to investigate causes of casualties and to find out most effective prevention measures. Risk analysis is widely used in many areas; in case of marine technology it is used routinely in off-shore technology.

The author investigates possibilities to apply risk analysis in the area of ship handling with the focus on human factor. This is preliminary study where possible methodology for hazards identification and risk assessment in respect of CRG casualties are investigated and risk control options are suggested. Various aspects of the influence of human factor in collision avoidance are listed and in particular the effect of training is stressed.

1 INTRODUCTION

During last three decades attention of the maritime world has been focused on safety of shipping. Amongst other causes of accidents at sea casualties related to manoeuvrability happen quite often and analysis of casualties shows that CRG casualties (Collisions-Ramming-Groundings) constitute about 53% of all serious accidents leading to ship loss (Payer 1994). Data on CRG casualties for the year 1982 analysed on the basis of sources provided by LRS and DnV revealed that their frequency was rather high as it is seen from the Table 1.

The data showed that 1 ship in 22 took part in CRG casualty this year (Samuelides 1984). CRG casualties occur more often with increasing speed and size of vessels and such casualties may cause more serious consequences. Collisions may also happen more often in restricted waterways and canals and in particular in areas where additional external factors, as e.g. current, make handling of ships more difficult.

Statistics of CRG casualties in the following years showed considerable decrease in percentage, however it revealed quite alarming increase of the number of accident during last few years. As it is seen from Fig.1

Table 1. Data on CRG casualties.

Source	Mean number of ships during the year	Number of CRG casualties	Frequency of casualties [%]
DnV	2816	120	4.3
LRS	3391	170	5.0

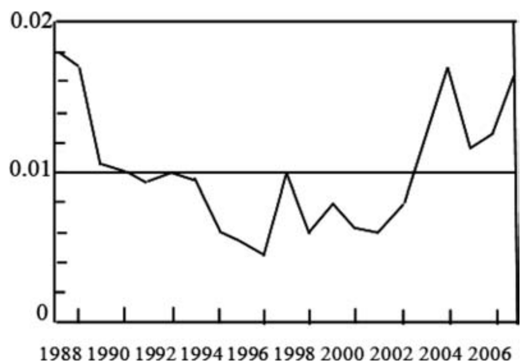

Figure 1. Percentage of CRG casualties during years 1988–2006.

the number of such casualties has increased almost twice from the year 2000. The reason of this effect is not clear – it may be, however, to be attributed to increase of the size of ships, in particular container ships operated, to the increase of the density of traffic, but most probably to the lower level of performance of crew members which were recruited from many different countries.

This situation requires serious attention and prevention of CRG casualties must be treated as a priority.

2 SAFETY SYSTEM OF PREVENTION OF CRG CASUALTIES

In order to achieve safe operation of ships and preventing casualties holistic and system approach is

Table 2. Five-tier system for goal-based requirements.

Tier I:	Goals
Tier II:	Functional requirements
Tier III:	Verification criteria of compliance
Tier IV	Technical procedures and guidelines, classification rules and industry standards
Tier V	Codes of practice and safety and quality systems for shipbuilding, ship operation, maintenance, training etc

necessary. System approach consists of looking at the problem as assembled of the number of sub-problems mutually interrelated. In this approach the process of achieving main goal is exactly defined and related to sub-problems in accordance to the adopted plan.

The system of safety against CRG casualties is rather complex, because of numerous interrelations between various sub-systems and because of that, its analysis is difficult. It would be, however, necessary to take into account in this system at least the following sub-systems:

– Traffic pattern
– Environment
– Human factor
– Equipment
– Legislation

3 GOAL ORIENTED APPROACH

The weak point of the present legislative status of safety requirement in general was duly noticed by highest IMO (International Maritime Organization) bodies and quite recently the Marine Safety Committee (MSC) recommended adoption of the concept of goal-based approach to safety requirements. The goal-based approach does not include prescriptive regulations or standards that must be complied with, but sets goals that allow alternative ways of achieving safety (Hoppe 2006). Goal-based standards are for some time considered at IMO and appraised by some authors (Vassalos 2002), and they were introduced in some areas, albeit not in the systematic manner. Marine Safety Committee commenced in 2004 (IMO 2004) its work on goal-based standards in relation to ship construction adopting five-tier system (Table 2).

IMO MSC committee agreed in principle on the following Tier I goals to be met in order to build and operate safe and environmentally friendly ships: "Ships are to be designed and constructed for a specific design life to be safe and environmentally friendly, when properly operated and maintained under specified operating and environmental conditions, in intact and specified damage conditions, throughout their life" (IMO 2004).

In the opinion of the author goal oriented holistic approach appears to be the best solution in preventing the increase of the number of CRG casualties. Goal oriented approach involves apart of prescriptive requirements, also risk analysis and system approach. Therefore to investigate the possibilities of application of risk analysis to safety against CRG casualties and to investigate possible risk control options and associated requirements is an important issue.

4 PRESCRIPTIVE VERSUS RISK-BASED APPROACH

The basic dichotomy in the conception of safety requirements consists of prescriptive approach and risk-based approach (Kobyliński 2007).

Traditional regulations were of prescriptive nature and they are formulated in the way where a certain standards related to ship construction or operation must be complied with. Prescriptive regulations could be developed on the basis of experience (experts opinions) statistics, analytical methods, computer simulation, model tests and full-scale trials. Deterministic or probabilistic calculations may be employed when developing the criteria, although, as a rule, deterministic approach is used in most cases.

Prescriptive regulations have many advantages. They are formulated in a simple language, which is easily understood by everybody, they are easy in application, they also make checking adherence to the requirements easy. The main shortcoming of prescriptive regulations is that they are bounding designers or operators and they do not allow introduction of alternative solutions. They are based on experience gained with existing objects and they are not suitable for novel types of ships or uncommon operational and emergency situations. Usually they were amended after serious casualties happened. The risk involved with the application of prescriptive regulations is not known.

At the opposite of the prescriptive regulations, there is risk-based requirements. The risk-based requirements are based on risk analysis where and the main object is to assess eventually accept the risk. The advantages of risk-based requirements is that they are not binding designers or operators requesting to satisfying or obeying adopted fixed rules and standards, but offering the possibility of applying a variety of solutions provided they ultimately allow to keep risk within acceptable limits. Human factor could be taken into account, which is extremely important because the majority of CRG casualties may be attributed to human fault.

Risk is defined as a product of hazard probability and hazard severity (consequences):

$$\mathbf{R = PxC}$$

To facilitate the ranking and validation of ranking IMO recommended defining consequence and probability indices on a logarithmic scale (IMO 2002). The risk index may therefore be established by adding the probability (frequency) and consequence indices. We have then:

$$\mathbf{Log(risk) = Log\ (frequency) + Log(consequence)}$$

Table 3. Risk assessment matrix.

	Hazard probability (hourly) ←Low				High→
	E.	D.	C.	B.	A.
I Catastrophic	Z	Y	X	X	X
II Critical hazardous effect	Z	Z	Y	X	X
III Marginal major effect	Z	Z	Z	Y	Y
IV Negligible minor effect	Z	Z	Z	Z	Z

Risk-based approach according to IMO recommendation is formalized (FSA methodology) and includes the following steps (IMO 2002):

1 Identification of hazards
2 Risk assessment
3 Risk control options
4 Cost-benefit assessment, and
5 Recommendations for decision making

FSA methodology was recommended by IMO for general evaluation of safety requirements; in particular cases strict adherence to this methodology may not be possible. However, in all cases risk analysis must lead to risk assessment and acceptance. For this purpose, and taking into account specifics of ship operation at sea, risk assessment matrix (Table 3) may help to evaluate risk and to take appropriate action. In this matrix hazard probabilities are divided in five groups, as below:

– *A. Frequent* – always occurring, once or more yearly (greater than 10^{-3}–10^{-4})
– *B. Probable* – few times during ship's lifetime (10^{-4}–10^{-5})
– *C. Occasional* – once during the lifetime of the ship, few times in the lifetime of the fleet (10^{-5}–10^{-7})
– *D. Remote* – little probable, but possible during the lifetime of the ship, once during the lifetime of the fleet (less than 10^{-7})
– *E. Extremely improbable* – such a small probability that it may not be taken into account (10^{-9}–10^{-10})

and hazard severities (consequences) into four groups (Halebsky):

1 *Catastrophic* – loss of vessel, fatalities
2 Critical hazardous effect – dangerous degradation in handling, need outside rescue operation
3 *Marginal major effect* – significant degradation in handling but not preventing to complete safely journey
4 *Negligible minor effect* – slight degradation in handling, need for slight modification of operating procedures

In the table 3: Z- action to reduce hazard if economically feasible. Y-action to reduce hazard probability, X action to eliminate hazard

5 RISK ANALYSIS AND SAFETY AGAINST CRG CASUALTIES

At present there are numerous requirements included into various legislative instruments that were, however, developed at different times by different bodies, some of them being compulsory, some others have only status of recommendations and in general, they are not consistent in many points. Most of them were developed by the International Maritime Organization, but in spite of that, holistic system approach was not used in their development. The list of different legislative instruments where requirements applicable to safety against CRG casualties are included is shown below:

– IMO manoeuvring standards,
– SOLAS convention requirements related to steering gear, and machinery
– COLREG convention requirements
– Pilotage requirements
– Separate traffic routes
– STCW Convention (Personnel qualifications)
– SOLAS Equipment Chapter Port authorities requirements.

The above list is not exhaustive and is provided as an example only. Requirements included in all of the above instruments are of prescriptive character.

Because of the complicity of the system of legislative instruments and requirements included therein, direct application of risk analysis to the system as a whole at this stage seems to be extremely difficult and requiring thorough study that is beyond the scope of this paper. Risk analysis might be, however, applied for example to the requirements related to the following subsystems:

– Ship design – (manoeuvring characteristics)
– Harbour and traffic lanes design
– Effect of human factor.
– Navigational aids
– Performing safe manoeuvers

The above subsystems are strongly interconnected, but in order to bring practicable solution they may be separated at the first step.

6 APPLICATION OF RISK ANALYSIS TO PERFORMING SAFE MANOEUVRES

The first step of the risk analysis is identification of hazards and assessment of their probabilities. Analysis of CRG casualties reveals that the causes of casualty may be attributed to:

– functional aspects resulting from reliability characteristics of the technical system, therefore manoeuvring characteristics of the ship,

- operational aspects resulting from the way the ship is operated in traffic routes, from harbour lay-outs and facilities, cargo handling etc,
- human factor, i.e. aspects resulting from action of the personnel handling the system, therefore crew members but also ship management, marine administration and owners company organization
- external causes resulting from factors independent from designers builders and operators of the technical system therefore from ship environment and climatology
- decision support systems helping the master or pilot to take appropriate decisions, *inter allia* radar. ARPA, electronic maps, computer programs for manoeuvres prediction, etc.

IMO resolution included general guidance on the methodology of hazard identification. With respect to manoeuvrability, hazard identification could be achieved using standard methods involving evaluation of available data in the context of functions and systems relevant to the type of ship and mode of its operation.

- Hazard identification is carried-out using hazard identification and ranking procedure (HAZID). According to general recommendation the method of hazard identification comprised mixture of creative and analytical techniques. Creative element was necessary in order to ascertain that the process is proactive and is not limited to hazards that happened in the past. Analytical techniques are used in order to evaluate, separately or in combination:
- statistical data concerning causes of accidents
- historical data including detailed description of accidents
- conclusions resulting from model tests and computer simulations
- event and fault trees method
- opinions of experts

In particular the last method is much of use, provided that collation and analysis of expert opinions is properly organized – for example by using Delphic method (IMO 2002a).

US Coast Guard (USGC 1981) provided some indication on the posible causes of CRG casualties. This is shown in the table 4.

The classification shown in Table 4 is, however, not particularly useful for the purpose of risk assessment because large percentage of casualtied was classified as unavoidable. This is certainly wrong, because there is always some cause behind the casualty and it is probably that human and organisation errors (HOE) or heavy weather and perhaps other causes qualified by marine courts as "*force majeure*" are hidden in this category.

As an example of application of this methodology the list of hazards in respect to CRG casualties is shown in Fig. 2. In this example ranking of hazards is not shown, moreover the sketch could be considered as the first level of the fault tree leading to CRG.

Table 4. Causes of CRG casualties (according to USGC 1981).

	Cause	Percentage [%]
Insufficient ship controllability	Wind & current	9
	Turning ability	7
	Tugs	4
	Stopping	4
	Bank suction	3
	Sterring failure	2
	Control while stopping	2
	Control while backing	2
Direct human error		33
Unavoidable		34

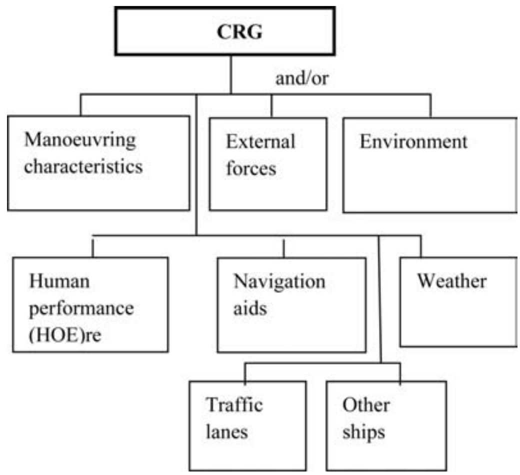

Figure 2. First level fault tree for CRG casualties.

Hazards identified as relevant to safety against CRG are all strongly interconnected, moreover, human factor understood as performance of an individual (in most cases the master) plays important part in each case. Hazards identified should be further decomposed preferably using fault trees and/or events trees reproducing various scenarios of CRG casualty. The set and combination of fault trees and event trees as developed for all hazards identified and all scenarios (defined as risk contribution trees – RCT) is a basis for HAZOP (hazard and operability study) procedure that allows also assessment of frequencies (probabilities) of hazards required for risk assessment. This is rather tedious task bearing in mind the multitude of possible scenarios. This problem, however, is not discussed here.

7 EFFECT OF HUMAN FACTOR

As human and organization errors (HOE) are major causes of CRG casualties they require a special attention. HOE may be the result of design and construction faults (bad manoeuvring characteristics of ships) and *force majeure*, that are responsible for about 20%

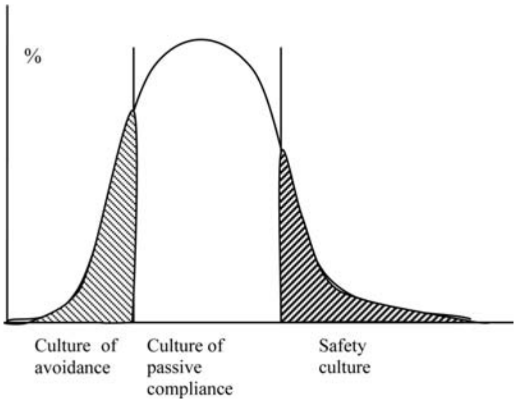

Figure 3. Effect of safety culture on accidents rate.

of all HOE casualties (Payer,1994), the rest may be attributed to operational factors that include the following:

– society and safety culture
– organization
– system
– individual

Society and its culture has important effect on safety. Economic factors tend to limit safety requirement, because enhancement of safety cost more; from the other hand lower safety level results in higher cost of increased number of accidents. There exists certain optimum from the purely economic point of view, but if fatalities are resulting from accidents the pure economic point of view is no more valid and crucial point is how high risk may be acceptable by the society. The risk is much lover in developed countries in comparison with the countries that are not yet developed.

The society culture is strongly related with safety culture. High safety culture helps to avoid a large percentage of accidents. The enquiry by the RINA amongst a number of naval architects did show, that the majority of them recognized safety culture as the most important factor in safety (The Naval Architect 1999).

Organization. A great number of accidents is caused by bad management or bad organization. Bad organization could mean lack of supervision, lack of procedures, lack of instructions, lack of activity by marine administration, lack of policy for safety management or lack of motivation. One important factor is also culture of shipping company. For example the dominant culture of company might be tendency to achieve gain without considering risk (flirting with risk) or forcing excessive strain leading to over-fatigue and in consequence may appear to be opposite with the aim of the company.

System. The following system faults influence operator behaviour: complexity, faulty signalization, small tolerances, difficult operation, inaccessibility, high demands in operation, wrong alarms, bad visibility, incomplete software, etc.

Table 5. Human error factors (Bea 1994).

Fatigue	Wishful thinking	Bad judgement
Negligence	Mischief	Carelessness
Ignorance	Laziness	Physical limitations
Panic	Violations	Boredom
Greed	Drugs	Inadequate training
folly	Inadequate communication	Inadequate education
Ego	Alcoholism	Hidden illness

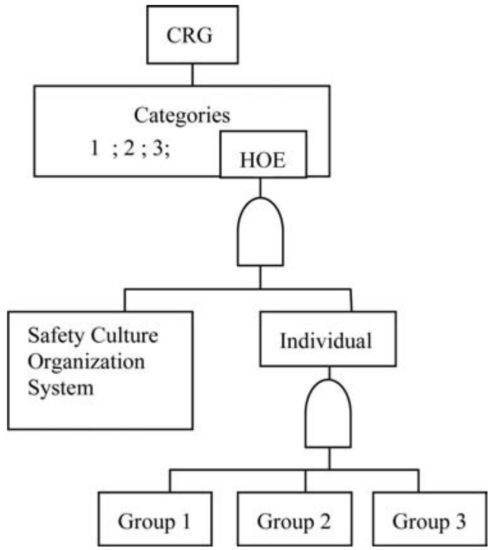

Figure 4. Simplified fault tree for HOE.

Individual. Operator’s error is the most common cause of accident. However it is very difficult to identify the real reason of the operator action. There is a long list of possible causes as shown in table 5.

It is really impossible to attach probabilities to all factors listed in Table 5, because the relevant statistical data do not exist and there is no chance that such statistics will be ever available. However all the above factors may be divided in three groups:

1 individual character of the operator- integrity, reliability, morale
2 physical predispositions – health, endurance, immunity
3 knowledge – education, training, experience

Limiting to the above three groups it would be possible to construct the risk contribution tree (fault tree) for HOE as shown in fig 4.

For the risk analysis it is necessary to attach probabilities to every group at the first stage. This could be done on the basis of statistics or expert opinions. Currently published statistics is not available, although major shipping companies certainly have such data. If probabilities attached to each of the above groups are known then conclusions with regard to risk o may be drawn.

Risk control options constitute an important step in the risk analysis. If we assume that probabilities are equally distributed between three groups, then concentrating on group three for example, one risk option would be stressing importance of training. Amongst other effects, it is well known, that training affects considerably the ability to handle critical situations (Bea 1984).

8 CONCLUSIONS

Risk analysis is an excellent method for analyzing safety of complex systems to which system of safety against CRG casualties at sea also belongs. However application of risk analysis to CRG casualties poses serious difficulties because of the complexity of the system and strong interrelations between different subsystems.

In particular, human factor, playing predominant part in a great majority of CRG accidents, requires special attention in the risk analysis. This is, however, difficult because of lack of reliable statistical data on the influence of various individual characteristics of the man at control on safe performance of manoeuvres. There are intuitive conclusions that training, for example affects ability of the man at control considerably, but respective statistical data are not available.

Nothwithstanding the difficulties, even at this stage, risk analysis could provide useful results when applied to various subsystems of safety against CRG casualties and in particular it may allow to assess the impact of various risk control options. This may be, in particular, relevant to human and organization errors (HOE) as shown in the paper.

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13.4 Estimation of the probability of propulsion loss by a seagoing ship based on expert opinions

A. Brandowski & W. Frąckowiak
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The event of the loss of propulsion function has been defined as hazardous event to a seagoing ship. It has been formalized. The procedure of acquisition of expert opinions on frequency of the event occurrence has been described. It may be considered to be of a numerical-fuzzy character. The fuzzy part was transferred to the numerical form by the pair comparison method. An example of the ship propulsion system comprising a low speed internal combustion engine and a solid propeller illustrates the method presented. It may be used wherever a hazard analysis has to be performed of a system involving human and technical aspects and there is a shortage of objective data on the investigated object.

1 INTRODUCTION

Loss of the propulsion function by a ship is one of the most serious categories of *hazardous events** in shipping. In specific external conditions it may lead to a loss of ship together with people aboard. The loss of propulsive power may be an effect of the propulsion system (PS) failures or of errors committed by the crew in the system operation process. In the safety engineering language we say that the *propulsion loss probability* depends on the reliability of the PS and of its operators. Determination of that probability is in practice confronted with difficulties connected with shortage of data on that reliability. This pertains particularly to the cases of estimation in connection with decisions taken in the ship operation. In such cases we have to rely on subjective estimations made by persons with practical knowledge in the field of interest, i.e. *experts*. The experts, on the other hand, prefer to formulate their opinions in the linguistic categories, in other words in the language of *fuzzy sets*. The author's experience tells also that in the expert investigations it is difficult to maintain proper correlation between the system data and the system component data. The paper presents a method of the subjective estimation of propulsion loss probability by a ship, based on the numerical-fuzzy expert judgments. The method is supposed to ensure that proper correlation. It is adjusted to the knowledge of experts from ships' machinery crews and to their capability of expressing that knowledge.

The method presented has been developed with an intention of using it in the decision taking procedures in risk prediction during the seagoing ship operation, in the shortage of objective reliability data situations.

* *Hazardous event* is defined as an event bringing about damage to human beings as well as to the natural and/or technical environment. It is also called "accident" or "initiating event".

2 DEFINITION OF THE SHIP PROPULSION LOSS AS A HAZARDOUS EVENT

The propulsion hazard is connected with the loss by the PS system of its capability of performing the assigned function, i.e. generating the driving force of a defined value and direction. It appears as an effect of a *catastrophic failure*** of the PS. Such failure may *cause immediate* (ICF) or *delayed* (DCF) stoppage of a ship. In the latter case the stoppage is connected with renewal, which may be carried out at any selected moment. It is obvious that only the former case of the forced stoppage creates a risk of damage or even loss of ship – it is a hazardous event.

We will relate the probability of ICF to an arbitrary time interval determined by the analyst. For instance, it may be duration of one trip, time interval between the ship class renewal surveys or one year, as it is usually assumed in risk analyses. Such an approach is useful in the ship operation risk management process.

The ICF type failure consequences may be divided into casualties and incidents (IMO 1997). In general, the ship casualties are non-repairable at sea by means of the ship own resources and may have very serious consequences, with the ship towing at the best and the loss of ship at the worst. The problem of consequences is not the subject of this paper.

The ICF type failure frequency depends mainly on the type of PS and the ship operation mode (liner trade, tramping etc.). On the other hand, the consequences are strongly dependent on the ship size and type and the environmental conditions, first of all the water region, season, time of day, atmospheric and sea conditions. They are also dependent on the navigational decisions and on the type and fastening of cargo in the holds and

** *Catastrophic failure* is defined as loss of the capability of performing by the object of its assigned function.

on deck. In general, these are the factors connected with the type of shipping carried out and the shipping routes the ship operates on.

3 FORMAL MODEL OF ICF EVENT

We assume the following:

- We are interested only in the "active" phase of ship operation, when it is in the shipping traffic. We shall exclude from the model the periods of stays in ship repair yards or in other places connected with renewals of the ship equipment.
- The investigated PS system may be only in the active usage or stand-by usage state. The ICF type PS failures may occur only in the former state.
- A formal model of the ICF type PS failures is the homogeneous Poisson process (HPP). This assumption is justified by the expert elicited data, which indicate that this type of failures occur fairly often, several times a year, but their consequences in general mean only a certain loss of operation time. More serious consequences, causing longer breaks in the normal PS system operation, occur seldom. The exponential distribution of time between failures, taken place in the HPP stream model, is characteristic of a normal operation of many system classes, including also the ship systems (Gniedienko B.W. & Bielajew J.K. & Solowiew A.D. 1965, Modarres M., Kaminskiy M. & Krivtsov V. 1999). It is appropriate in the case when the modeled object failures and the operator errors are fully random abrupt failures and not gradual failures caused by the ageing processes and/or wear of elements. This corresponds with the situation when scrupulously performed inspections and renewals prevent the latter type of failure from occurring.
- Experts are asked only about two numerical values: number of ICF type failures N(t) during time period t = 1 year (8760 hours), and the time at sea percentage share κ 100% during their seamanship period – this is within their capability of answering.
- The opinions on the failures of PS system components are elicited in the linguistic form.

The seagoing ship system active usage time t(a) is strongly correlated with the specific ship operational state times, mainly with the "at sea" state including "sailing", "maneuvers" and "anchoring". The following approximation may be adopted for the system, also for the PS:

$$t^{(a)} = t^{(m)} = \kappa t, \tag{1}$$

where $t^{(a)}$ = active usage time; $t^{(m)}$ = time at sea; t = calendar time of the system observation; $\kappa = t^{(m)}/t$ = time at sea factor ($\kappa \in \langle 0, 1\rangle$).

In view of these assumptions, the ICF type PS failures may occur only in the system active usage state, i.e. for the PS system in the $t^{(m)}$ time, although their observed yearly numbers are determined by experts in relation to the calendar time t. The model ICF probability has the vector form:

$$P\{t^{(a)}\} = P\{\kappa\ t\} = \\ = \left[\frac{(\lambda^{(a)} \kappa\ t)^k}{k!} e^{-\lambda^{(a)} \kappa t} : k = 1,2,\ldots,\ K \right] \tag{2}$$

where $\boldsymbol{P}\{t^{(a)}\}$ = the vector of probabilities of ICF type event occurrence within time interval $\langle 0, t)$; $\lambda^{(a)} \approx \sum_{j=1}^{J} N_j(t)/\kappa_j\, t_j$ = intensity function of HPP (ROCOF) (and at the same time the failure rate of the exponential distributions of time between failures in that process, [1/h]; N_j = annual number of the ICF type events elicited by *j-th* expert, [1/y]; κ_j = time at sea factor elicited by *j-th* expert; t_j = calendar time of observation by *j-th* expert [h]; J = number of experts; K = the maximum number of possible ICF type failures in the time interval $\langle 0, t)$; t = the time of probability prediction.

The $\lambda^{(a)}$ formula is based on the theorem on the asymptotic behaviour of the renewal process (Gniedienko B.V., Bielajev J.K. & Soloviev A.D. 1965):

$$\lim_{t \to \infty} \frac{E[N(t)]}{t} = \frac{1}{T_o} = \lambda, \tag{3}$$

where T_o = mean time between failures.

The number of ICF type events in the $\langle 0, t)$ period may be 0,1,2,…or K with well-defined probabilities. The maximum of these probabilities is the assumed measure of the probability of ICF type event occurrence:

$$P_{\max}\{t^{(a)}\} \max_{k \in \{1,2,\ldots,K\}} \frac{(\lambda^{(a)} \kappa t)^k}{k!} e^{-\lambda^{(a)} \kappa t} \tag{4}$$

The λ and κ parameters determined from the elicited opinions may be adjusted as new operation process data arrive on the investigated system failures.

Expressions (2) and (4) allow to estimate the probabilities of ICF type hazardous events in the determined time interval t. Another problem is estimation of the risk of consequences of these events, i.e. damage to or total loss of the ship and connected human, environmental and financial losses. This is a separate problem not discussed in this paper.

4 DATA ACQUISITION

The PS will be further treated as a system consisting of subsystems and those consisting of the sets of devices.

Experts are asked to treat the objects of their opinions as anthrop-technical systems, i.e. composed of technical and human (operators' functions) elements. They elicit their opinions in three layers in such a way that proper correlation is maintained between data of the system and data of the system components. In layer 0 opinions are expressed in numbers, in layers I and II – in linguistic terms. For layers I and II separate *linguistic variables* (LV) and *linguistic term-sets* (LT-S) have been defined (Piegat A. 1999).

Layer 0 – includes PS as a whole.

Estimated are the annual numbers of type ICF type failures of PS $N(t)$ and the percentage share of time at sea κ 100% in the time of expert's observation.

Layer I – includes decomposition of PS to a subsystem level.

- LV = share of the number of subsystem failures in the number of type ICF failures of PS.
- LT-S = A*1*-very small/none, B*1*-small, C*1*-medium, D*1*-large, E*1*-very large.

Layer II – includes the decomposition of subsystems to the sets of devices (set of devices is a part of subsystem forming a certain functional entity whose catastrophic failure causes catastrophic failure of the subsystem – e.g. it may be a set of pumps of the cooling fresh water subsystem).

- LV = *share of the number of failures of the sets of devices in the number of catastrophic failures of the respective PS subsystem.*
- LT-S = *A2-very small/none, B2-small, C2-medium, D2-large, E2-very large.*

The structure of data acquisition procedure presented here implies a series form of the reliability structures of subsystems (layer I) and sets of devices (layer II). Elements of those structures should be so defined that their catastrophic failures cause equally catastrophic failures of the PS system and subsystem respectively. The division into subsystems and sets of devices should be complete and disjunctive.

The data acquisition procedure presented here takes into account the expert potential abilities. It seems that their knowledge should be more precise in the case of a large operationally important system, as the PS is, and less precise as regards individual components of the system.

5 ALGORITHM OF EXPERT OPINION PROCESSING

In layer 0 the experts elicit annual numbers of the ICF type failures, which, in their opinion, might have occurred during 1 year in the investigated PS type:

$$N_j(t) \quad j = 1,2,...,J \tag{5}$$

and shares of the time at sea in the calendar time of ship operation:

$$\kappa_j \; 100\% \quad j = 1,2,...,J \tag{6}$$

where j = experts index; J = number of experts.

These sets of values are subjected to selection due to possible errors made by the experts. In this case a statistical test of the distance from the mean value may be useful, as in general we do not have at our disposal any objective field data to be treated as a reference set.

If the data lot size after selection appears insufficient, it may be increased by the bootstrap method (Efron & Tibshirani 1993).

From the data (5) and (6), parameters $\lambda^{(a)}$ and κ of expression (2) and (4) are determined. Number of opinions J may be changed after the selection.

In layer I experts elicit the linguistic values of subsystem shares in the number of ICF type failures of the investigated PS type (they choose LV value from the $\{A1, B1, C1, D1, E1\}$ set). The data are subjected to selection.

The elicited data with linguistic values are compared in pairs – estimation of each subsystem is compared with estimation of each subsystem. The linguistic estimations are transformed into numerical estimations according to the following pattern:

$$LT - S = B1 \Rightarrow 2,$$

$$LT - S = C1 \Rightarrow 3,$$

$$LT - S = D1 \Rightarrow 4,$$

$$LT - S = E1 \Rightarrow 5.$$

Numerical estimates of each subsystem are subtracted from estimates of each subsystem. In this way the difference values are obtained, which may have the following values: −4, −3, −2, −1, 0, 1, 2, 3, 4. Those differences are transferred into preference estimates (as given in Table 1) in accordance with the following pattern:

$4 \Rightarrow 9$, *absolute preference,*

$3 \Rightarrow 7$, *clear preference,*

$2 \Rightarrow 5$, *significant preference,*

$1 \Rightarrow 3$, *weak preference,*

$0 \Rightarrow 1$, *equivalence,*

$-1 \Rightarrow 1/3$, *inverse of weak preference,*

$-2 \Rightarrow 1/5$, *inverse of significant preference,*

$-3 \Rightarrow 1/7$, *inverse of clear preference,*

$-4 \Rightarrow 1/9$, *inverse of absolute preference.*

Table 1. Expert preference estimates acc. to Saaty (1980).

Estimate	Preference
1	Equivalence
3	Weak preference
5	Significant preference
7	Strong preference
9	Absolute preference
Inverse of the above numbers	Inverse of the above described preference

From these differences, by the pair comparison method, a matrix of estimates is constructed. The estimates depend on the "distance" of the linguistic values LT-S of a given variable LV. For instance, preference A1 in relation to E1 has the value 9 assigned, in relation to D1 a value 7, in relation to C1 a value 5. in relation to B1 a value 3 and in relation to A1 a value 1. The inverses of those preferences have the values, respectively: 1/9, 1/7, 1/5, 1/3 and 1. The matrix of estimates is approximated by the matrix of weight quotients of the sought arrangement. The recommended processing method is the logarithmic least squares method. The result is a vector of normalized arrangements of the subsystem shares (Saaty 1980, Kwiesielewicz 2002)***:

$$p = [p_1, p_2, \ldots p_i, \ldots, p_I], \tag{7}$$

where p_i = share of the *i-th* subsystem as a cause of an ICF type PS failure; I = number of subsystems.

Now we can determine in a simple way the intensity functions of individual subsystems arising from catastrophic failures:

$$\lambda_i^{(a)} = \lambda^{(a)} p_i, \; i = 1,2,\ldots,I. \tag{8}$$

In layer II experts elicit the linguistic values of subset shares in the number of catastrophic subsystem failures (they choose LV value from the $\{A2, B2, C2, D2, E2\}$ set). As in the case of subsystems, the expert opinions are processed to the form of normalized vectors of the arrangements of set shares:

$$\begin{gathered} p_i = [p_{i1}, p_{i2}, \ldots p_{ik}, \ldots, p_{iK}] \\ i = 1,2,\ldots,I \quad k = 1,2,\ldots,K \end{gathered} \tag{9}$$

where $\boldsymbol{p}_i$ = vector of the shares of *i-th* subsystem sets as causes of catastrophic failures of that subsystem; p_{ik} = share of the *k-th* set of *i-th* subsystem; K = number of sets in a given subsystem.

Then, the intensity functions of sets contained in individual subsystems arising from catastrophic failures are determined:

$$\lambda_{ik}^{(a)} = \lambda_i^{(a)} p_{ik} \quad i = 1,2,\ldots,I, k = 1,2,\ldots,K. \tag{10}$$

6 EXAMPLE

The example discusses investigation of a PS consisting of a low speed piston combustion engine driving a solid propeller, installed in a container carrier ship. Experts were marine engineers with long experience (50 persons). Special questionnaire was prepared for them containing definition of the investigated object, schematic diagrams of subsystems and sets, precisely formulated questions and tables for answers. It was clearly stated in the questionnaire that an ICF type failure may be caused by a device failures or by a crew actions. Out of 50 opinions elicited by experts, 3 were estimated as very unlikely (2 elicited numbers of the ICF events in a year were extremely underestimated and one was overestimated). They were eliminated and the remaining 47 opinions were further processed.

*** The Saaty method, criticised in scientific circles, is widely applied in the decision-taking problems.

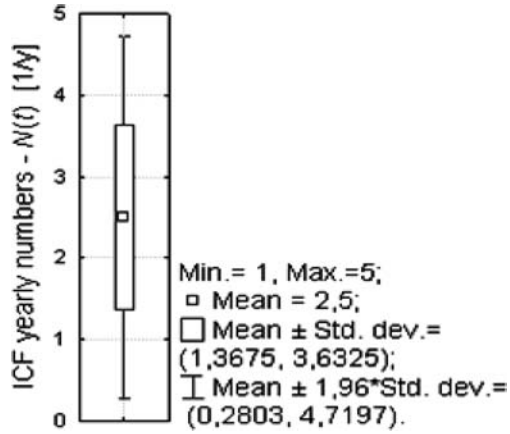

Figure 1. Box and whiskers plot of ICF yearly numbers.

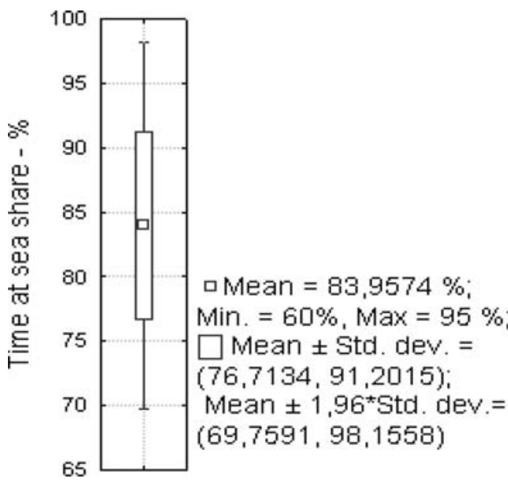

Figure 2. Box and whiskers plot of time at sea share.

Figs. 1 and 2 present statistical estimates of the expert opinion data (5) and (6).

Table 2 contains averaged basic data elicited by 47 experts in relation to the PS as a whole and the model parameters of ICF type event probability (equation (2)) determined from these data.

From the Table 2 data the probabilities of determined numbers of ICF type event occurrences in 1 year were calculated. Fig. 3 diagram presents results of those calculations. The numbers of probable ICF events in 1 year are equal 1, 2, …, 5. The maximum probability is 0.2565, which stands for 2 ICF type events during 1 year, and the probability that such event will not occur amounts to 0.0821.

Table 2. Basic results of propulsion system investigation.

Averaged expert elicited data	$\overline{N}(1\,y) = 2,5$ $\sigma[N(1\,y)] = 1,1325$ $\bar{\kappa}\ 100 = 83{,}95745\%$ $\sigma[\kappa\ 100] = 7{,}24406\%$
Risk model Parameters	$\sum_1^{47} t = 411720\,h$ $\lambda^{(a)} = 3,39922\ E - 04\ 1/h$ $\bar{\kappa} = 0{,}83957$

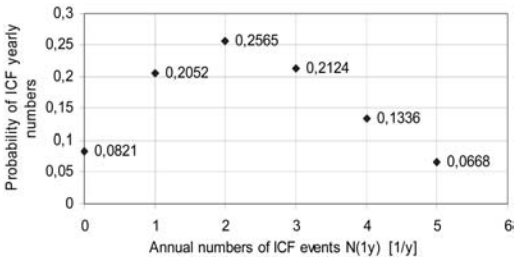

Figure 3. Distribution of ICF event numbers' probability.

Table 3. Intensity functions of the subsystems.

No	Subsystem	p_i	$\lambda^{(a)}10^{-5}$
1	Fuel oil subsystem	0,1330	4,5203
2	Sea water cooling subsystem	0,0437	1,4852
3	Low temperature fresh water cooling subsystem	0,0395	1,3426
4	High temperature fresh water cooling subsystem	0,0620	2,1074
5	Starting air subsystem	0,0853	2,9006
6	Lubrication oil subsystem	0,0687	2,3352
7	Cylinder lubrication oil subsystem	0,0446	1,5147
8	Electrical subsystem	0,1876	6,3770
9	Main engine	0,1987	6,7536
10	Remote control subsystem	0,1122	3,8146
11	Propeller + shaft line	0,0247	0,8410

Table 3 contains the subsystem intensity function (ROCOF) data calculated from equation (8). The main PS risk "participants" are main engine and the electrical subsystem and the least meaningful is the propeller with shaft line. This is in agreement with the experience of each shipbuilder and marine engineer.

Table 4 contains the fuel supply subsystem intensity function (ROCOF) data calculated from equation (10).

7 SUMMARY

The paper presents a method of subjective estimation of the hazard connected with losing by a seagoing ship of the propulsion function capability. The estimation is based on opinions elicited by experts – experienced marine engineers. The method is illustrated by an example of such estimation in the case of a propulsion system with a low speed piston combustion engine and a solid propeller installed in a container carrier.

The given in section 6 do not raise any objections. The authors do not have at his disposal sufficient objective data to evaluate precisely the adequacy of those data. It has to be taken into account that results of a subjective character may, by virtue of the fact, bear greater errors than the objective results achieved from investigations in real operational conditions.

The presented method may be used in the procedures of the ship propulsion risk prediction. It allows to investigate the impact of the PS system component reliability on the probability values of ICF type event. It may also be used with other types of ship systems and not only to ship systems, particularly in the situations of hazardous event probability estimations with insufficient objective data at hand.

In this place the authors thank Prof. Antoni Podsiadlo and Dr. Hoang Nguyen for their cooperation, particularly in the scope of the acquisition of expert opinions and their processing.

Table 4. Intensity functions of the fuel oil subsystem sets.

No	Set	p_{ik}	$\lambda_{ik}^{(a)}10^{-6}$
1	Fuel oil service tanks	0,0488	2,2062
2	Fuel oil supply pumps	0,1672	7,5572
3	Fuel oil circulating pumps	0,1833	8,2840
4	Fuel oil heaters	0,0944	4,2666
5	Filters	0,1540	6,9599
6	Viscosity control arrangement	0,2352	10,6323
7	Piping + heating up steam Arrangement	0,1172	5,2965

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13.5
Finite discrete Markov model of ship safety

L. Smolarek
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The ship safety modeling is the process used to convert information from many sources about the ship as an antropotechnical system into a form so that it can be analyzed effectively. The first step is to fix the system (ship, human, environment) boundaries to clearly identify the scope of the analysis. The ship can be generally defined by conceptual sketches, schematics drawings or flow diagrams to establish the element hierarchy which evolves from the physical and functional relationships. The man could be generally defined by the operational procedures. The environment could be generally defined by the mission place and time of the year. The information is needed considering that the accidents are caused by factors associated with ship (failure, design defect), man (human error, workload), and environment. Safety is a system property that we intuitively relate to a system's design, accident rates and risk. This work proposes finite discrete Markov model as an example of systematic approach to the analysis of ship safety.

1 INTRODUCTION

The safety of the ship system could be considered as a series of barriers or against the potential for failure. These barriers may include hardware, software, and the human element and the presence of one or more of the barriers will prevent accidents from happening. But it happens that the safety barriers are penetrated and an accident occurs.

Very often when an incident has occurred, once tends to interpret the past, prior to the event, only in terms of its bearing on that event which means that the total contemporaneous context is missing. So once concentrate only on "significant" event's chains.

2 THE SYSTEM

2.1 *The ship system*

The ship safety model should cover the ship geographically and all the installed systems including propulsion and electric power production, energy production, emergency power, bridge systems, safety systems, human factor and passenger related systems.

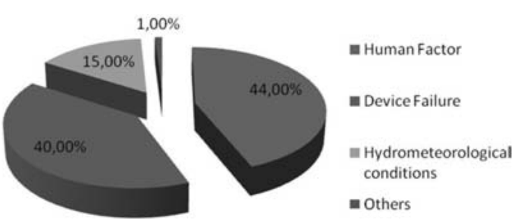

Figure 1. Ships accident statistic, *American Bureau of Shipping, 2004.*

The necessary methodology consists of following stages, (Soares, Teixeira, 2001):

1 Generic Ship Model
2 Topographical Safety Block Diagram
3 Ship Safety Model

Generic Ship Model describes how all the ship functions, subsystems and systems, influence the ship safety. Importance of each component should be clearly defined. Generic Ship Model could be further utilized as a basis for comprehensive Ship Safety model.

Specific criteria should be developed to enable efficient estimation of the crew influence on the ship safe factor.

2.2 *Navigational system*

Since half on twenty century rules concerning vessel technical condition, crew knowledge and operational action proving vessel safety are have been defined by

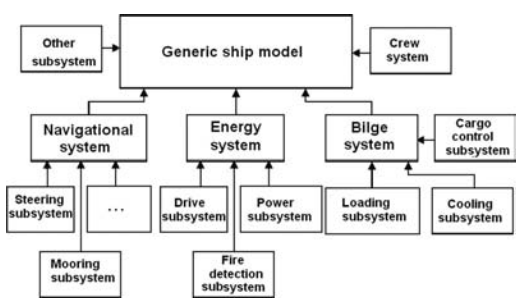

Figure 2. Generic model of some ship's subsystems and systems.

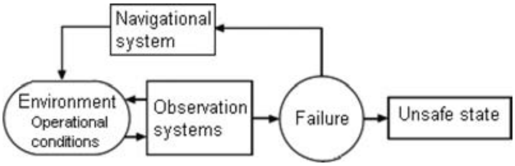

Figure 3. Vessel reliability conditions according to navigational system and navigational situation.

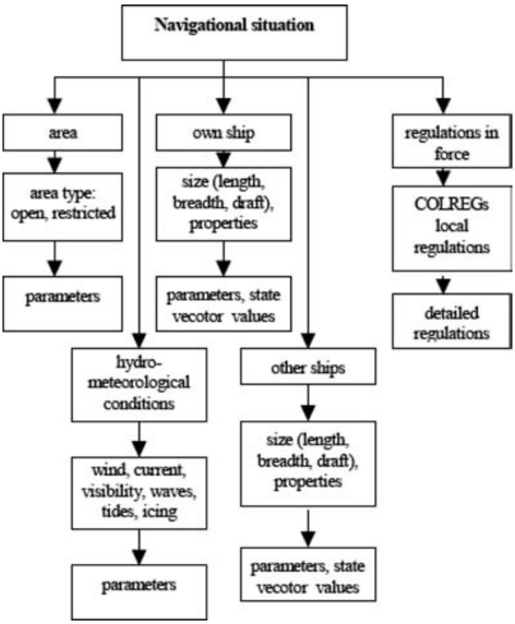

Figure 4. Model of ship encounter situations (Pietrzykowski 2007).

International Maritime Organization. The measure of vessel safety is a risk defined as a function of threats and consequences relating to theoretical and actual risk, (Soliwoda 2008).

2.3 *Human error*

Human reliability is one of main factors which influence safety at maritime transport. Generally we can select the sources of human error into intended and unintended.

Unintended errors can be classified as :

1 Errors of Omission
   – Involve failure to do something.

2 Errors of Commission
   – Involve performing an act incorrectly.

3 Sequence Error
   – Involve performs some step in a task or tasks out of sequence.

4 Timing Error
   – Involve fails to perform an action within an allotted time or performing too fast or to slow.

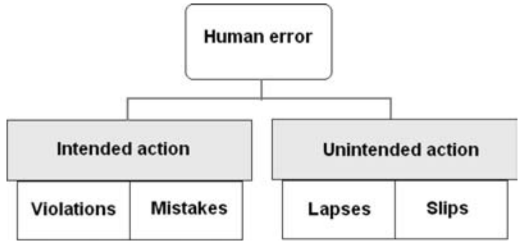

Figure 5. Sources of human error.

Table 1. Human errors sources statistic, ABS REVIEW AND ANALYSIS OF ACCIDENT DATABASES: 1991–2002.

Sources	%
Situation assessment and awareness	15,2
Task omission	10,4
Management	10,1
Knowledge, skills, and abilities	7,3
Mechanical / material failure	6,6
Weather	6,6
Complacency	5,6
Risk tolerance	4,8
Business management	4,8
Navigation vigilance	4,6
Lookout failures	4,3
Maintenance related human error	4,1
Fatigue	3,5
Unknown cause	3,3
Procedures	2,8
Manning	2,0
Commission	1,5
Uncharted hazard to navigation	1,3
Substance abuse	1,3

Factors Contributing to Accidents, (Clemens 2002)

– Management
– Physical Environment
– Equipment Design
– Work Itself
– Social/Psychological Environment
– Worker/Co-worker
– Unsafe Behavior/Chance (Risk)

Exposure to Hazardous Situation, (Lawton, Miller, Campbell 2005)

– Perception of Hazard
– Cognition of Hazard
– Decision to Avoid
– Ability to Avoid
– Safe Behavior

Probability of operator error (Clemens 2002)

$$Q\left(\frac{t}{T_m}\right) = \exp\left\{-\left(\frac{t - a_1 \cdot T_m}{a_2 \cdot T_m}\right)^{a_3}\right\} \quad (1)$$

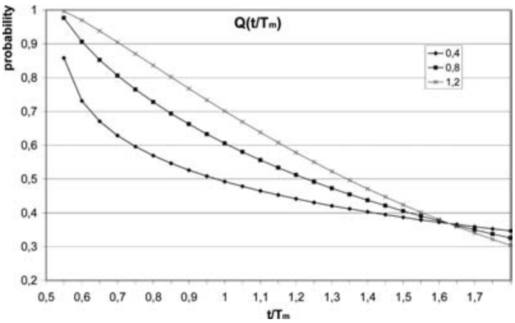

Figure 6. Probability of operator error for different skills and knowledge parameters, (Smolarek & Soliwoda, 2008).

where:

- a_1, a_2, a_3 are parameters connected with factors such as skills, knowledge, regulations;
- T_m is an average time for analyzed operation;
- t is time which operator has for this operation.

Also the Human Cognitive Safety Model (HCSR) can be used as a method for computing factor of human's safety degree for the whole safety degree of HMESE, (Wang Wuhong, et al 1997). If the uncertainties of human's conduct operation are taken into consideration, the error probability of human cognitive activities can be re-written as (Wang Wuhong, et al 1997):

$$P_h(t)=\begin{cases}\exp\left\{-\left(\dfrac{\exp\left[\ln\left(t/\hat{T}_{1/2}\right)-\sigma_u\Phi^{-1}(x)\right]-C_{\gamma_i}}{C_{\eta_i}}\right)^{\beta_i}\right\} & \text{when } t\geq C_{\gamma_i}\hat{T}_{1/2}\exp\left[\sigma_u\Phi^{-1}(x)\right]\\ 1.0 & \text{when } t< C_{\gamma_i}\hat{T}_{1/2}\exp\left[\sigma_u\Phi^{-1}(x)\right]\end{cases} \quad (2)$$

$$x=P_{h\gamma}\left\{P_h\leq P_h^{'}(t)\right\} \quad (3)$$

where:

- $\hat{T}_{1/2}$ – the most suitable estimated median of time required to complete the behavior;
- σ_u – logarithmic standard deviation of response time about operator;
- $\Phi^{-1}x$ ( ) reverse standard normal accumulation distribution function;
- x – ratio between defined probability and non-response.

3 SAFETY MODEL

Ship is the human-machine system in which the functions of a human operator (or a group of operators – crew) and a machine are integrated. In safe analysis it is necessary to emphases the view of such a system as a single entity that interacts with external environment so it's obvious to take into consideration, (Gucma, 2005). From the three aspects of "human", "machine", "environment", in this paper qualitatively analyses the influence of two aspects, human and machine on safety of Human-Machine-Environment System in the ship transportation process. The safety degree of a ship is the function of the three sub-systems about human, machine and environment and can be regarded as the functional system according to human error and technical failure. The human error and technical failure are express interaction human-environment and ship-environment, (Smolarek, 2008):.

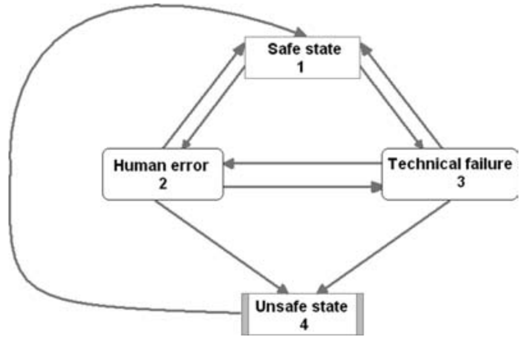

Figure 7. Graf of system state changes.

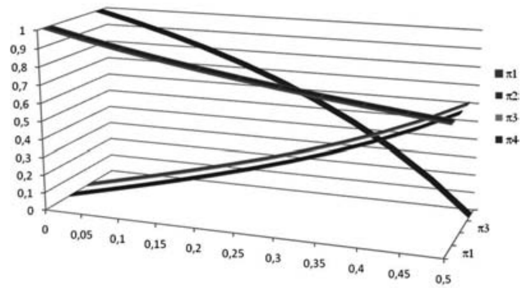

Figure 8. Graf of tendency of stationary state changes for increasing p.

The graph of ship system safety states changes is presented at figure 8. We take into consideration the ship safety model which is discreet in state and time domain.

Where state 2 is partially unsafe state according to human error and state 3 is partially unsafe state according to technical failure of the ship or its any subsystem.

Corresponding transition matrix of one-step transition probabilities

$$P=\begin{bmatrix}0 & p_{12} & p_{13} & 0\\ p_{21} & 0 & p_{23} & p_{24}\\ p_{31} & p_{32} & 0 & p_{34}\\ p_{41} & 0 & 0 & p_{44}\end{bmatrix} \quad (4)$$

According to matrix (4) we have

$$\begin{aligned} p_{12}+p_{13}&=1\\ p_{21}+p_{23}+p_{24}&=1\\ p_{31}+p_{32}+p_{34}&=1\\ p_{41}+p_{44}&=1\end{aligned} \quad (5)$$

Using the total probability and memoryless property of Markov chains we obtain the Chapman Kolmogorov equations

$$p_{ij}(k,k+n) = \sum_{r} p_{ir}(k,k+m) \cdot p_{rk}(k+m,k+n)$$
$$i,j \in \{1,2,3,4\}, 0 \le m \le n. \tag{6}$$

If it is an irreducible non periodic Markov chain consisting of *positive recurrent* states then a unique stationary state probability vector $\boldsymbol{\pi}$ exists

$$\pi = \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \end{bmatrix} \tag{7}$$

where:

– π_k – is a steady state probability, k = 1,2,3,4;

and the matrix equation for vector $\boldsymbol{\pi}$ is given by

$$\begin{bmatrix} -1 & p_{21} & p_{31} & p_{41} \\ p_{12} & -1 & p_{32} & 0 \\ p_{13} & p_{23} & -1 & 0 \\ 1 & 1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \tag{8}$$

where:

– p_{jk} – is a transition probability from state j to state k,j,k = 1,2,3,4.

If the condition

$$\det \begin{bmatrix} -1 & p_{21} & p_{31} & p_{41} \\ p_{12} & -1 & p_{32} & 0 \\ p_{13} & p_{23} & -1 & 0 \\ 1 & 1 & 1 & 1 \end{bmatrix} \ne 0 \tag{9}$$

is satisfied, then the solution is given by

$$\pi_1 = \frac{(p_{23}p_{32}-1)}{(1+p_{41})(p_{23}p_{32}-1)+(p_{13}p_{32}+p_{12})(p_{21}-p_{41})+(p_{12}p_{23}+p_{13})(p_{31}-p_{41})}$$
$$\pi_2 = \frac{-p_{12}-p_{13}p_{32}}{(1+p_{41})(p_{23}p_{32}-1)+(p_{13}p_{32}+p_{12})(p_{21}-p_{41})+(p_{12}p_{23}+p_{13})(p_{31}-p_{41})}$$
$$\pi_3 = \frac{-p_{13}-p_{12}p_{23}}{(1+p_{41})(p_{23}p_{32}-1)+(p_{13}p_{32}+p_{12})(p_{21}-p_{41})+(p_{12}p_{23}+p_{13})(p_{31}-p_{41})}$$
$$\pi_4 = \frac{p_{21}p_{32}p_{13}+p_{12}p_{23}p_{31}+p_{31}p_{13}+p_{23}p_{32}+p_{21}p_{12}-1}{(1+p_{41})(p_{23}p_{32}-1)+(p_{13}p_{32}+p_{12})(p_{21}-p_{41})+(p_{12}p_{23}+p_{13})(p_{31}-p_{41})}$$

If transition probabilities are equal to p, then

$$\pi_1 = \frac{1}{1+p}; \quad \pi_2 = \frac{p}{1-p^2}; \quad \pi_3 = \frac{p}{1-p^2}; \quad \pi_4^0 = 1-\frac{p}{1-p} \tag{10}$$

4 CONCLUSIONS

Vessel safety assessment carried out upon IMO standards allows theoretical estimating of safety without actual vessel conditions details and condition of crew. For more sophisticated cognitive modeling is necessary to model numerous failure modes or represent complex interdependencies between human error sources, ship route, ship technical and exploitations parameters. An alternative to representing the seaman as an element of a ship system is to represent him as a subsystem in and of itself. It means that the seaman should be modeled autonomously.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

13.6
The possibility of application of algorithms indicating maximum paths in directed graphs for modeling of the evacuation process

D.H. Łozowicka
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: In the introduction, ways of accounting geometrical, population, environment and procedure parameters in the computer evacuation simulating programs have been shown. In the part to follow the method for graph theory based representation of the geometry of escape routes has been described. Besides, means of indicating the longest time of emergency evacuation is proposed using a modified Warshall's algorithm to find the maximum weights in the directed graph. The use of the algorithm to indicate maximum escape routes makes it possible to verify the arrangement of escape routes in newly designed or existing ships.

1 INTRODUCTION

The trend in building very large passenger ships imposes a necessity for the safety systems of those vessels to be constantly improved. Sea voyages offer an attractive way of spending free time, therefore ensuring safety of people on board should constitute an ultimate goal to be pursued, also in case of emergency evacuation from a vessel. An analysis of factors affecting the evacuation process should precede the actual stage of designing a vessel so that the risks can be, at least partially, eliminated during ship operation. For buildings ashore the actual time of evacuating counts till the moment the building is left. For ships, this process should be divided into the following stages: proceeding to muster stations, abandoning vessel (embarkation on life–saving appliances and their launching or the same combined with evacuation slide system). The time in case of possible emergency evacuation of people should not exceed the time available to carry out the evacuation.

The analysis of evacuating people from a ship is very complex because it involves a large number of factors influencing the evacuation process and specific conditions related with the marine environment. Models accounting for potentially greatest number of factors affecting the evacuation process make it possible to obtain results close to reality. However, they are extremely difficult to verify. While conducting full scale evacuation trials we cannot hurt the volunteers, let them be affected by smoke, etc. which makes the results of those trials different from what can happen during the actual evacuation.

Theoretical analysis and actual trials of passenger ship evacuation (in order to verify the models) are carried out by research centres in collaboration with maritime administration, industry and transport. The development of evacuation analysis is coordinated by the International Maritime Organization (IMO).

From the point of view of population of people taking part in the evacuation, two approaches can be distinguished. In the first one, referred to as the global approach, people in motion are treated as a liquid (hydraulic) medium. The process of movement is described by a simple equation of flow kinematics (e.g. models: EVACNET4 (Kisco & Francis & Nobel, 1998), WAYOUT (Shestopal & Grubits, 1994)). In the individual approach the movement is analysed, often in association with a defined pattern of behaviour, separately for each participant of the evacuation (e.g. models: Simulex (Thompson & Marchant, 1995), PedGo (Meyer- König & Klupfel & Schreckenberg, 2001)).

The decision making process of people who take part in the evacuation is presented in the model on the basis of a relevant method for the simulation of human behaviour. The classification of models according to behavioural systems is as follows (Erica & Kuligowski & Peacock, 2005):

– without behavioural principles (only the aspect of movement is taken into consideration) e.g. models: EVACNET4, PathFinder (Cappuccio, 2000),
– alleged behaviour (models do not declare principles of behaviour, instead they assume them on the basis of alleged behaviour), e. g. models: PedGo, Simulex,
– behavioural system based on principles (system "if, then"), e.g. models: EXITT (Levin, 1998), E-SCAPE (Reisser-Weston, 1996),
– probabilistic behavioural system (principles included in the model are stochastic), e. g. CRISP (Fraser-Mitchell, 2001), ASERI models (Schneider & Konnecke, 2001),
– behavioural system based on artificial intelligence, e.g. models: Legion (Williams, 2005) Vegas (Still, 1994).

Evacuation models differ according to the way the movement of people is presented. In most types of models people have their specific travel speed (actual data). However, in the instances of a greater density leading to queuing there are various methods of describing the movements of people. In the situation of a restricted flow, the following approaches to modeling can be distinguished:

– determining the speed and flow of people (individuals or populations) on the basis of the geometry of the analyzed space (density), e.g. WAYOUT, STEPS (Hoffman & Henson, 1998) models,
– establishing individual distances between evacuating people and possible obstacles, e.g. SIMULEX, VEGAS models,
– calculating the undisturbed flow, then accounting for disturbances using various coefficients, e.g. ALLSAFE model (Heskestad & Meland, 1998).

In all models the surroundings of evacuation must be presented, i.e. the geometry of the interior (corridors, spaces layout). The space is divided into subspaces and each subspace is attached to the neighbouring ones. Usually two methods are employed:

– space is substituted for a network of polarized spaces of different shapes and sizes, depending on the model (e.g. PedGo, EGRESS models (Ketchell & Cole & Webber, 1994)), making it possible to locate an individual evacuated as well as possible obstacles by the determination of the exact position in the space (room),
– space is shown by means of fields which stand for spaces (rooms) or corridors and are not consistent with actual dimensions, giving the exact position of an evacuated person in a given space (room) is not possible; there is only a possibility to move between the components of the analyzed structure (e.g. EXODUS model (Gwynne & Galea & Lawrence & Filippidis, 1998)).

2 THE REPRESENTATION OF THE GEOMETRY OF SHIP'S ESCAPE ROUTES BASED ON THE GRAPH THEORY

On the basis of ship evacuation plan it is possible to present the layout of evacuation routes on the ship (corridors, stairways and spaces) in the form of a hydraulic network. In the next stage, utilizing the graph theory and accounting for the movement of passengers along escape routes, the layout of the escape routes is brought down to the format allowing for further use in the designed model of evacuation.

Particular stages of encoding the escape routes layout in the form of the directed graph is shown in Figure 1.

When using this kind of record, it is suggested that one of the ways of looking for the maximum evacuation path be employed to form the most disadvantageous scenario of evacuation, that is, to calculate the maximum weights of the graph. To this end the modified Warshall's algorithm was used (Ross, 2005).

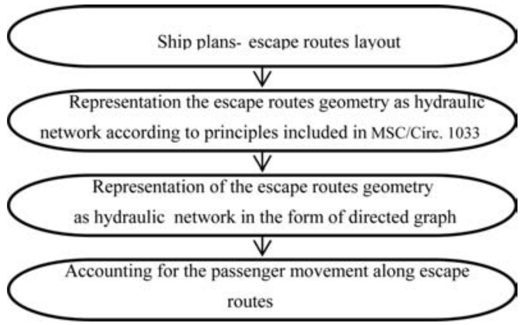

Figure 1. Algorithm of encoding the emergency escape routes arrangement into the form of the directed graph.

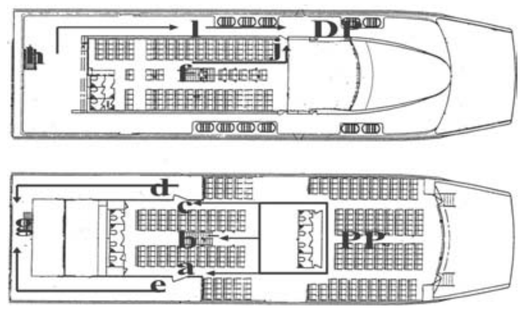

Figure 2. Escape routes arrangement together with the direction of the evacuation.

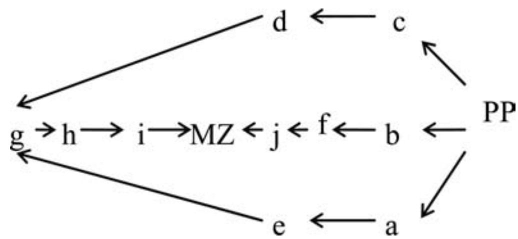

Figure 3. The escape routes arrangement is represented as a digraph.

The devised method will be presented using a chosen vessel as an example.

In room PP there are 180 people, who split up the moment the evacuation commences and proceed through three exits: towards the staircase *b* and the doors *a* and *c*. Figure 2 shows the escape routes arrangement together with the direction of the evacuation.

The escape routes arrangement is represented as a digraph in which a set of vertices represents the particular sections of escape routes, while the edges represent the connections among them (Fig 3). In the digraph which represents escape routes, the weight of the edge can be interpreted as the walking time of a given evacuation group along this kind of path.

To calculate the time of evacuation T_c , the method of calculating the flow of people through respective nodes of the arrangement was used.

The time of the transit of *x* passengers along a given arc (passageway, space) is:

$$T_c = \frac{L}{S_{śr}} + \frac{x}{(F_s \cdot W_c)} \tag{1}$$

where: $S_{śr}$ – mean speed of people along the escape routes can be assumed as ca. 0.5 m/s when the ship is listing (Yoshida& Murayama & Itakaki, 2001), (Ando& Ota & Oki, 1988),
L – the length of passageways
W_c – the breadth, measured betwen the handrails, for the passageways and stairways, and the door breadth when fully open,
F_s – specific flow is assumed to be 0.43 (person/ms) (acc. SFPE Fire Protection Engineering Handbook, 2nd edition, NFPA 1995),

The time obtained should be increased by coefficients accounting for: passenger age, passageways inaccessibility, restricted visibility, flow of people in the opposite direction and other factors which may hinder the evacuation.

The increasing coefficients are assumed to be 2.3 (IMO, Circular MSC/Circ.1033).

The table of the weights of the analyzed example has the following form:

$$\begin{bmatrix}
-\infty & 363 & 343 & 363 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & 357 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 312 & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & 357 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 147 & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 147 & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 361 & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 556 & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 204 & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 428 \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 357 \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty
\end{bmatrix}$$

The symbol ∞ indicates that in the graph there is no path between given vertices.

3 WARSHALL ALGORITHM FOR FINDING THE MAXIMUM PATHS

In connection with the intended adaptation of the Warshall algorithm for finding the maximum paths all cases of ∞ were replaced by values $-\infty$, whilst $-\infty + x = -\infty = x + (-\infty)$ for a given x and $-\infty < a$ for all real numbers *a*.

The maximum weight is called the largest weight of path leading from one vertix to the other and is denoted as M.

The general formula of the Warshall algorithm to form the table of the maximum weights of the graph is as follows (Ross, 2005):

{Data: matrix W_0 of non-negative edge weights of the directed graph without loops and multiple edges}
{Results: matrix M the weight of maximums of this graph}
{Auxiliary variables: matrix W}

```
W:=W0
for k=1 n perform
   for i=1 up to n perform
      for j=1 up to n perform
         if W[i,j]<W[i,k]+W[k,j], then
            replace W[i,j] with the sum W[i,k]+W[k,j]
M:=W
```

The calculations of the maximum weights functions table of the analysed example are as follows:

$$W = W_0 = \begin{bmatrix}
-\infty & 363 & 343 & 363 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & 357 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 312 & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & 357 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 147 & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 147 & -\infty & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 361 & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 556 & -\infty & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 204 & -\infty & -\infty \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 428 \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & 357 \\
-\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty
\end{bmatrix}$$

Due to the fact that we deal with a sequence of events, the algorithm is to be simplified because we focus only on the maximum paths coming out of the vertix PP, that is, we assume that $i = 1$.

$W_1=$

$$\begin{bmatrix} -\infty & 363 & 343 & 363 & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty & -\infty \end{bmatrix}$$

$W_2=$

$$\begin{bmatrix} -\infty & 363 & 343 & 363 & 363 & 720 & 363 & 363 & 363 & 363 & 363 & 363 \end{bmatrix}$$

$W_3=$

$$\begin{bmatrix} -\infty & 363 & 343 & 363 & 363 & 720 & 675 & 363 & 363 & 363 & 363 & 363 \end{bmatrix}$$

etc.

As a result, the following maximum weights from the vertix PP are obtained.

M=

$$\begin{bmatrix} -\infty & 363 & 343 & 363 & 363 & 720 & 675 & 867 & 1423 & 1627 & 1373 & 2055 \end{bmatrix}$$

In the analyzed example of escape routes arrangement the longest time of evacuation amounts to 2055 s (ca. 34 minutes). The longest evacuation time there is for the following paths:

PP-a-e-g-h-i-MZ
PP-c-d-g-h-i-MZ

We assume that each of those paths is passed by 60 persons. Those groups of people achieve following time of moving by analyzed edges of graph:

PP-a (PP-c) -343 seconds
c-d (a-e) – 357 seconds
d-g (e-g) – 147 seconds
g-h – 556 seconds
h-i – 204 seconds
i-MZ – 428 seconds

Alternative paths (PP-b-f-j-MZ) is definitely shorter than above mentioned.

4 CONCLUSION

The purpose of the paper was to present an application of the Warshall algorithm to calculate the longest time of evacuation on the ship.

The ship evacuation plan can be presented in the form of a digraph with assigned weighted edges of the graph. Then, by applying one of the algorithms determining maximum paths, the longest evacuation time can be set for assumed evacuation scenarios.

The analysed example was simplified by an assumption that the evacuees would split up proportionally to head for the available exits. However, it is not seldom that everyone chooses one particular egress (so called "herd instinct"), leaving the remaining ones unused. This can ultimately lead to congestions or decelerating the evacuation. Therefore this phenomenon is to be taken into account in further studies.

The method of representing the evacuation routes arrangement as a digraph and the application of the algorithm to determine the maximum paths enables the design solutions of escape routes to be verified both for newbuildings and ships in operation.

At present it is mandatory to carry out an evacuation analysis for passenger vessels of the ro-ro and high speed craft type. However, in the future it is intended to include all passenger vessels carrying more than 1000 people. It shows that further studies on modeling the evacuation process are needed, which is justified by the fact that evacuation scenarios recommended by the IMO are inaccurate and have proved inadequate to real-life situations.

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Chapter 14. Marine transportation

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

14.1 Maritime transport development in the global scale – The main chances, threats and challenges

A.S. Grzelakowski
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: International transport is a subject to many regulatory measures worked out by governments, international organisations (e.g. IMO, ILO, EU), regional institutions and public entities. As a result, such regulatory mechanism, which is getting throughout international, strongly affects the real sphere of maritime transport as well as its productivity and efficiency. Maritime transport operators have to apply to many new standards and rules set by international public regulators aimed mainly at improving and enhancing safety and security at sea. It is sometimes very painful process in terms of costs and time but inevitable to survive in the highly competitive environment. The author analyses the nowadays existing regulatory mechanism in maritime transport and tries to evaluate it in terms of its impact on effectiveness of maritime transport processes.

1 INTERNATIONAL MARITIME TRANSPORT AND ITS GROWING ROLE IN THE GLOBAL ECONOMY

1.1 *The international seaborne trade and world maritime transport in the global supply chains*

Maritime transport remains the backbone of international trade and the global economy, supporting strongly the ongoing processes of globalization. It has strong position in global supply chains, determining to great extent their effectiveness and elasticity (see fig. 1). In 2007, the volume of international seaborne trade reached 8.02 billion tons. It means that over 80 per cent of world merchandise trade by volume is being carried by sea.[1] The recent growth in trading commodities volume transported by sea – a 4.8 per cent increase year-on-year – was higher than recorded in the last decades. Indeed, during the past three decades, the annual average growth rate of world seaborne trade is estimated at 3.1 per cent.[2] Still relatively strong demand for maritime transport services is fuelled by growth in the world economy and international merchandise trade being stimulated by dynamic increase in production and consumption in the main world centers (see fig. 1). In 2007, the world gross domestic product (GDP) grew at 3.8 per cent while world merchandise exports expanded by 5.5 per cent over the previous year.[3]

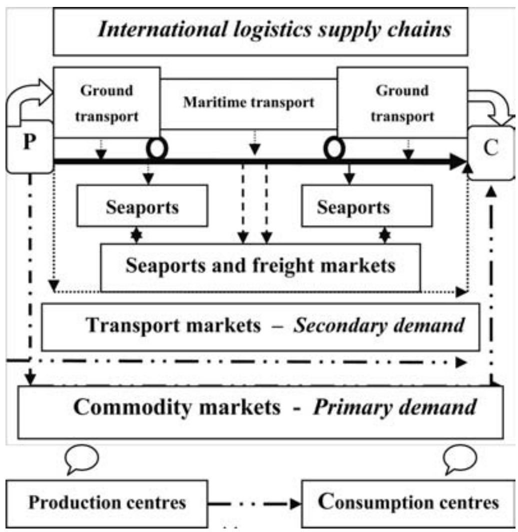

Figure 1. International maritime transport in the global logistics supply chains.

In the recent years economic growth was driven primarily by emerging developing countries and transition economies. It has proceeded, despite rising energy prices with their potential implications for transport costs and trade and despite growing global risks and uncertainties. There were many other factors determining increase in economic activity worldwide. Among them factors such as soaring non-oil commodity prices, the global credit crunch, a depreciation of the US dollar, and an unfolding food crisis should be count. The world economy and trade have, so far,

[1] 2008. *Review of Maritime Transport 2008*. Report by the UNCTAD secretariat. UNCTAD/RMT/2008, New York and Geneva 2008, p. 14.

[2] *Ibidem, p. 17–18.*

[3] *Ibidem, p. 21*

sustained all these negative tendencies with sufficient resilience.

As a result of growing world economy and consequently international seaborne trade, the world merchant fleet expanded by 7.2 per cent during 2007 to 1.12 billion deadweight tons (dwt) at the beginning of 2008. It means that the world tonnage grew 1.5 times faster than the word merchandise trade in volume terms carried by sea. In 2007 historically high demand for shipping capacity was reached. The shipping industry responded to growing needs of the global supply chains by ordering new tonnage. It applied predominantly to the dry bulk vessels. All types of vessel orders were at their highest level ever, reaching over 10,000 ships with a total tonnage of almost 500 million dwt, including 222 million dwt of dry bulk carriers.[4] Such a huge influx of new tonnage into the world fleet over recent years has contributed to the decrease in the average age of the world fleet to 11.8 years. This tendency, despite the ongoing global financial and economic crisis will be continued in the next years.

It is to some extent a result of very high dynamic of growth in container shipping. The world containership fleet reached in mid of 2008 approximately 13.5 million TEUs, of which 11.5 million TEUs were on fully cellular containerships. This fleet includes 54 containerships of 9,000 TEU and above, which are operated by five companies: CMA CGM , COSCON and CSCL, Maersk and MSC.[5]

1.2 *The main tendencies and occurrences in the development of maritime transport in the global scale*

Characteristic feature of the contemporary maritime transport, as far as vessels' ownership is concerned, is very high concentration of the world tonnage in a relatively small group of countries. As of January 2008, nationals of the top 35 ship owning countries together controlled 95.35 per cent of the world fleet. It is a slight increase over the previous year figure. All external factors unequivocally indicate that such tendency will gradually go ahead in the next years, partially as an effect of still growing international competition and already achieved position of the main shipping countries (economies of scale). Greece continues to maintain its predominant position, followed by Japan, Germany, China, and Norway; together, these five countries hold a market share of 54.2 per cent.

Due to the still ongoing flagging out practices in the world scale, the controlled by nationals of the ship-owning countries tonnage is, however, spread in second and many open and international registers run by foreign countries, so called *flag of convenience.* Due to that, 32 per cent of the Greek controlled fleet use the national flag, versus 68 per cent using foreign flags. The Japanese-controlled fleet is 93 per cent foreign flagged. The German-controlled fleet uses a foreign flag for 85 per cent of it tonnage. More than half of the German controlled fleet is comprised of containerships (50.7 million dwt). As regards the Norwegian-controlled fleet with 46.9 million dwt, which still maintaining its fifth- place ranking. 69.7 per cent of this tonnage, is registered under a foreign flag, and the remaining 30.3 per cent mostly under the Norwegian International Ship Register (NIS). The Chinese-controlled fleet is 40 per cent registered in China, versus 60 per cent that uses a foreign flag.

The 35 economies with the largest fleets registered under their flag account for 1,033 million dwt, corresponding to 92.42 per cent of the world fleet. The top 5 registries together account for 49.3 per cent, and the top 10 registries account for 69.5 per cent of the world's dwt. It means that the level of concentration of worldwide flagged out tonnage and reregistered in the countries running open, international ships registers is almost similar to the group of main ship-owning (controlling) countries.

The 10 largest open and international registries that cater almost exclusively to foreign-controlled ships are Panama, Liberia, the Bahamas, the Marshall Islands, Malta, Cyprus, the Isle of Man, Antigua and Barbuda, Bermuda, and Saint Vincent and the Grenadines. Although they are in principle open to vessels from practically any country, most of them in fact specialize in some countries of ownership, or in certain vessel types.[6] Among the top 35 registries, 15 cater almost exclusively for nationals of their own country. They are e.g. Greece, China, the Republic of Korea, India, Germany, Japan, Italy and the United States. A low participation of foreign-controlled tonnage may be due to two reasons. First, the country's laws may not allow for the use of its national flag if there is no adequate "genuine link" between flag and ownership. Second, although the country's registry might in theory be open to foreigners, its tax or employment regime or other regulations may make the registry unattractive to foreign ship owners. Finally, among the top 35 flags of registration, there are three "second" or "international" registries, i.e. registries that allow for the use of the national flag, albeit under conditions that are different from those applicable for the first national registry.

[4] The tonnage of dry bulk ships on order at the end of 2007 was 12 times higher than it was in June 2002; since mid-2007, dry bulk orders outstrip those for any other vessel type. See: *Review of Maritime Transport 2008.* Op. cit., p. 45,

[5] Twelve of them have a capacity of more than 10,000 TEU; these include eight 12,508 TEU ships owned and operated by Maersk, and four vessels of 10,000 to 10,062 TEU, owned and operated by COSCON. Comp. *Review of Maritime Transport.* Op. cit., p. 45,

[6] E.g. more than half the tonnage registered in Antigua and Barbuda is on containerships, mostly from German owners. The registries that cater mostly for dry bulk carriers are Bermuda, Cyprus, Malta, Panama and Saint Vincent and the Grenadines; Panama alone accounts for 33.3 per cent of the world dry bulk tonnage, mostly from Japanese owners. Oil tankers account for the largest tonnage in the registries of the Bahamas, the Isle of Man, Liberia and the Marshall Islands. Comp. *Review of Maritime Transport 2008*. Op. cit., p. 62,

Table 1. Operational productivity of the total world fleet in the period 1970–2007 (selected years).

Year	Tons carried per dwt	Thousands of ton-miles performed per dwt
1970	7.9	32.7
1980	5.4	24.6
1990	6.1	26.0
2000	7.5	29.7
2006	8.0	32.8
2007	7.7	31.6

Source: Calculations on Lloyd's Register-Fairplay, Fernleys *Review and Review of Maritime Transport 2008*, p. 61.

They include notably the Norwegian International Ship Register (NIS), the Danish International Register of Shipping (DIS), and the French International Register (RIF). While the DIS is almost only used by Danish-controlled ships, both the NIS and the RIF also cater to some foreign-controlled tonnage.

The above indicated tendencies noticed in the international maritime transport on its supply- and demand side as well as in its contemporary existing regulatory mechanism, especially relating to merchant fleet distribution on the basis of tonnage ownership (real control) and vessels registration (fleet management), have great impact on world fleet operational productivity and its effectiveness. As maritime transport constitutes very important link in global supply chains, servicing the primary markets (see fig. 1), such trends and tendencies have to influence significantly efficiency and elasticity of logistics supply chains and the international seaborne trade. To examine the scope and intensity of their impact on secondary and primary markets use by global supply chains, indices of operational productivity for the world fleet need to be analyzed.

The main indexes of this kind are defined in tons and ton-miles per deadweight ton (dwt).[7] They show the still changing relations between the growth in the supply of tonnage and the growth in total seaborne trade as well as in ton-miles performed by the world fleet, which corresponds with a distance one ton was carried over. Consequently, as the growth in the supply of the fleet outstrips the growth in total seaborne trade (it befell e.g. in 2007) the tons of cargo carried per deadweight ton (dwt) decreases. In 2007 the global average of tons of cargo carried per dwt of cargo carrying capacity was 7.7 (see tab. 1); in other words, the average ship was fully loaded 7.7 times during that year. During the same year, the ton-miles performed per deadweight reached 31.6; thus, the average dwt of cargo carrying capacity transported one ton of cargo over a distance of 31,600 nautical miles in 2007, i.e. 87 miles per day.

[7] Grzelakowski A. S., Transport morski w gospodarce światowej."*Przeglad Komunikacyjny*" 2008 No. 12, p. 6–7

Table 2. Tonnage oversupply in the world shipping in selected years (percentages).

Year	1990	2000	2004	2005	2006	2007
	9,7	2,3	0,7	0,7	1,0	1,1

Source: Elaborated on data presented *by Lloyd's Register – Fairplay* and *Lloyd's Shipping Economics* as well *Review of Maritime Transport 2008*. p. 65.

The indices of operational productivity of the world fleet presented in tab. 1 indicate that it varies significantly on the yearly basis. It is a result of freight markets dynamic which reflects the perpetual changing in supply and demand for shipping services (fig. 1) and indirectly is connected with the level of overcapacity generated by shipping operators accomplishing a strategy of flexible and efficient demand fulfillment on the highly competitive freight markets. The level of world tonnage overcapacity (tonnage oversupply) presents tab. 2.

Explaining the changing operational productivity in the world tonnage, it is worthy to note too, that ship operators usually in response to high oil prices, are interested in reduction the service speeds of their vessels, thus saving fuel. Such a strategy was typical for shipping operators, e.g. especially in liner shipping in 2007. However, with lower service speeds, more vessels are required on a given route, which on one hand helps to reduce overcapacity, while at the same time leading to a reduced operational productivity. Capacity constraints and congestion at ports also have a negative impact on the fleet's productivity, as ship capacity is tied up while queuing. All these factors stemming from primary and secondary markets (fig. 1) – their dynamic and forms of existing connections have influenced the level of operational productivity of the world merchant fleet.

Eventually, as regards world maritime transport development and global tendencies viewed in that sector of the world economy, it is necessary to emphasise that it generates costs to shippers, i.e. exporters and importers of goods carried by sea, hence determining to some extend the final commodities' prices in overseas consumption centers. Total transport costs implicating costs of carriage goods on sea routes, contribute significantly to shaping the volume, structure and patterns of trade as well countries' comparative advantages and trade competitiveness (see fig. 1).[8]

The share of global freight payments in import value has reached on the average 5.7 per cent in the world

[8] Ports and International Transport Costs. *UNCTAD Transport Newsletter* No. 31, March 2006 and Recent Trends in Liner Shipping Freight Rates.*Transport Newsletter* No. 24, June 2004, Hummels D., Transportation Costs and International Trade in the Second Era of Globalization, *Journal of Economic Perspectives*. Volume 21, Number 3, 2007, p. 131–154;

scale in the recent five years.[9] It was higher than it the previous years due to the fact that the rate of increase in the world total value of imports (*c.i.f*) was more than two times lower over the foregoing years than the growth rate of total freight paid for transport services. Developing countries and economies in transition have recorded the highest freight costs. Freight costs expressed as a percentage of the value of imports for both country groups, have reached almost 8.0 per cent, while developed countries have the lowest freight costs, which are estimated at ca. 5.1 per cent of the value of imports in last two years. It is a result of still existing significant diversification in the commodity structure of external trade between well and less developed countries.

While bulk trade, including tanker and dry cargo dominates world seaborne trade, containerized trade, as a fast growing market segment, is at the heart of globalized production and trade. Containerized goods are mostly manufactured goods, which tend to have higher value per volume ratios than bulk cargoes – like oil and other commodities – and travel longer distances, as they are sourced more globally.[10] Given their higher value, on average, transport costs on valorem basis matter less for high value goods than low value raw materials. Therefore, if higher transport cost were to lead to regionalization, lower value manufactured goods (clothing, textile) would likely be much more affected than higher value goods or goods, the production of which involves significant capital or start up costs.[11]

Higher transport costs are of more relevance for bulk cargo. To minimize the incidence of transport costs on low-value/high-volume goods, importers of bulk cargo are more likely to source from nearby providers. For example, oil requirements in the Americas are more likely to be sourced from locations such as South America or Mexico or, in Asia, from neighbouring Asian oil exporting countries.[12]

Future developments in transport costs, production and trade patterns will depend, *inter alia,* on: a) the rise in oil prices and other relevant factors including the potential for substitution of oil by more affordable alternative sources of energy; b) the share of transport costs in the overall production costs; c) whether shifting production closer to the market is cost efficient, i.e. whether transport cost savings outweigh the potential rise in production costs (wage differentials, cost of energy used in production, environmental regulation) and, importantly, d/ the type of goods traded/ transported (e.g. bulk or manufactured), their value, weight, handling requirements.[13]

2 REGULATORY MECHANISM OF THE INTERNATIONAL MARITIME TRANSPORT

2.1 *The main forms, mechanisms and instruments of maritime transport regulation in the global scale*

The above indicated tendencies and occurrences typical for this link of international maritime supply chains stem from many factors influencing this sector of the world economy. Among them the most important one is a regulatory system of the maritime transport, that in short, mid and long term plays a steering role of its real sphere. In illustrative form its structure and character presents fig. 2.

The regulatory sphere (system) of maritime transport consists of two subsystems, i.e. public, central subsystem and autonomous, market subsystem (fig. 2). The first one, basing on public regulatory mechanism, comprises in fact maritime transport policy, being regarded as domestic (national) and international regulatory instrument of the real sphere in maritime transport sector. The role of international maritime transport policy formed by international organizations (IMO, ILO, WTO, ISO) as well as many regional and sub-regional organizations, institutions, associations, entities etc., such as EU, ESCA, EASA, EMSA, etc.) has been absolutely dominant in the public regulatory mechanism in recent years. It is due to the fact, that maritime transport is one of the most internationally oriented transport modes. It operates in the global scale and generates global challenges and threats (maritime accidents, oil spillage, waste disposal at sea, etc.) which can be solved only by international organizations launching binding international standards and norm with respect to widely perceived safety at sea and security issues.

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[9] See: *Review of Maritime Transport 2007*. UNCTAD. New York and Geneva 2007, p. 11.

[10] In 2006, the share of manufactured goods exported globally amounted to over 70 per cent of the value of world exports ($8.2 trillion out of a total of $11.5 trillion). Comp. World Trade Organization (WTO), Statistics Database, Merchandise Trade by Commodity, 2006 (www.wto.org).

[11] Korinek J., Clarifying Trade Costs in Maritime Transport, Working Party of the Trade Committee, OECD, 25 April 2008.

[12] See Rohter, L, Shipping Costs Start to Crimp Globalization, *International Herald Tribune*, 2 August 2008:

[13] UNCTAD/TC/WP(2008)10, Limão N. and Venables A J., Infrastructure, Geographical Disadvantage, Transport Costs and Trade, *Journal of Economic Literature*,

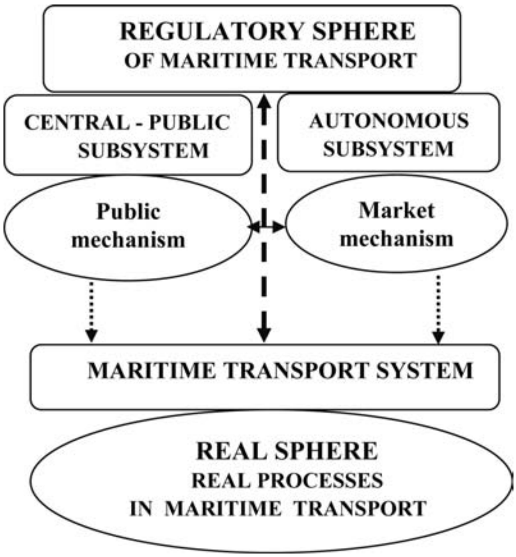

Figure 2. The regulatory mechanism of the international maritime transport.

internationally oriented transport modes. It operates in the global scale and generates global challenges and threats (maritime accidents, oil spillage, waste disposal at sea, etc.) which can be solved only by international organizations launching binding international standards and norm with respect to widely perceived safety at sea and security issues.

Beside international maritime policy, the real sphere in this transport sector, being a domain of thousands shipping operators, acting in global scale on the one hand but on the other being nationals of many shipping countries with their own economic interests in maritime transport development, has to be regulated by domestic public body (governments) in line with its national objectives. However, these objectives need to respect international maritime standards applying to technical, social, economic and environmental standards in shipping industry. Hence, nowadays the real magnitude of national transport policy is peripheral and in practice limited to those areas of regulatory mechanism which are actually outside international interests (taxation, registration fees, etc.).

Irrespective of public regulation, the real sphere of maritime transport is a subject of autonomous regulatory mechanism, i.e. mainly market mechanism (fig. 2). It is key driving force for supply and demand side, influencing short and long term behavior of shipowners and shippers in terms of operational and strategic decision making. Market mechanism is regarded as a dominant resources allocation instrument in maritime transport, which in fact determines demand distribution and its allotments to particular shipping operators and in the end defines their competitive position (competitive advantage), economic effectiveness and finally their financial yields.

Due to the significant demand fluctuations resulting from primary markets, the freight shipping market mechanism is very dynamic, influencing considerable demand and supply price elasticity. It is generally relatively low (lower in liner shipping sector than in irregular – tramp shipping), being in fact partially determined by the price elasticity of demand for commodities transported by sea. Primary markets – their dynamic on the supply and demand side – being serviced by maritime transport – to great extent assign demand fluctuation on secondary freight markets and in that way determine their dynamic. It applies to other markets as well, that usually have great impact on freight markets and can significantly indirectly influence the strategies of shipping operators in the global scale, changing their costs and incomes as well as their competitive advantages.

2.2 *Freight markets as an autonomous regulatory mechanism in the international maritime transport*

As it was earlier mentioned, market mechanism regulates the real processes in the maritime transport sector in short- mid- and a long run, influencing subsequently the behavior of shipowners and their decision making processes (market choices). Its impact on the real sphere in the global maritime transport was especially pronounced in recent two years, in that period, when bunker prices exploded, changing the previous cost structure dramatically to shipowners' disadvantage. These market changes and the forms of ship operators' reactions against such global market events, are presented below.

Fuel costs determine indirectly trade costs, as direct transport costs in the form of freight rates constitute, as earlier indicated, a fraction of the entire trade transaction costs. Maritime freight rates themselves are determined by many other factors, such as trade imbalances, economies of scale, levels of competition, port infrastructure, type and value of the goods traded etc. When ship bunkering prices in Rotterdam were 83 per cent higher in June 2008 than in June 2007, and the bunkering bills of major shipping lines were on average 67 per cent higher in the first quarter of 2008 than in the first quarter of 2007, fuel costs grew significantly, being estimated to account for more than half of the overall operating costs of a shipping company at that time.[14] According to Germanischer Lloyd, by November 2007, fuel accounted for 63 per cent of the operating costs of an 8,000-twenty-foot-equivalent-unit (TEU) container ship. It should be noted, however, that, because of the abundance of fuel oil in the world's major bunkering ports, ship bunker prices luckily did not hit the record levels of crude oil prices.

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[14] Benamara H., Valentine V., Fugeza M., Fuel prices, transport costs and the geography of trade. *UNCTAD Transport Newsletter.* Trade Logistics Branch. No. 39, Second Quarter 2008, p. 5–6.

At such conjuncture shippers were trying to ensure that containers are fully loaded, and they are using more cross-docking and intermodal rail.[15] These strategies are not only offsetting high energy costs, but are also used to obtain more efficiency and long-term sustainability from their distribution networks. As a result, no mechanism is in place to deflect the full effect of rising prices from maritime transport end users.

The maritime industry can, however, take action to avoid spiraling freight rates. The industry has already reacted to rising oil prices by reducing sailing speeds and by reorganizing services. It is estimated that a 10 per cent reduction in speed can lead to a 25 per cent reduction in fuel consumption.[16] According to Hapag-Lloyd, although a lower speed implied "longer voyages, extra operating costs, charter costs, interest costs and other monetary losses, slowing down still paid off handsomely".

Additionally, the shipping industry has been investing in more fuel-efficient technologies (hull design, propulsion, engines) and alternative energy sources. More recently, wind energy is attracting attention with giant kites being tested on some freighters (e.g. MV Beluga SkySails). By using the SkySails system, a ship's fuel costs can be reduced by 10 per cent to an annual average of 35 per cent, depending on wind conditions. Under optimal wind conditions, fuel consumption can temporarily be reduced by up to 50 per cent.[17] While the shipping industry may in some cases be able to absorb raising costs without passing them on to shippers, in general, cost- recovery measures in the form of bunker adjustment factor (BAF) charges are introduced.

Moreover, new opportunities to realize savings in transport costs may emerge in the context of global warming. The effect of rising oil prices and transport costs may be offset by savings that could be derived from full-year operation of the Northern Sea Route and the opening of the Northwest Passage.

The shortcuts offered by the new shipping lanes would cut transport costs and therefore benefit globalization and create further competition with existing routes such as the Panama and Suez canals. The Northwest Passage would offer a new route between Europe and Asia that is 9,000 km shorter than the Panama Canal route and 17,000 km shorter than the Cape Horn route. Taking into account canal fees, fuel costs, and other relevant factors that determine freight rates, the new trade lanes could cut the cost of a single voyage by a large container ship by as much as 20 per cent, from approximately US$17.5 million to US$14 million and would save the shipping industry billions of dollars a year.[18] The savings would be even greater for very large vessels that are unable to fit through the Panama and Suez canals and so currently sail around the Cape of Good Hope and Cape Horn.[19]

All above presented shipowners' strategies and forms of conducts and behaviors undertaken in response to market pressure, aimed at better supply-side applying to the new demand-side constellation, clearly reflect the real regulatory power of freight markets and their impact on maritime transport sector. Hence, in spite of growing globalization and internationalization of shipping industry, market mechanism appears to be still dominant regulatory power in maritime transport sector.

2.3 *International maritime transport policy and its regulatory role of global shipping industry*

International maritime transport policy, created directly or indirectly by international organizations (i.e. IMO, ILO, HELCOM, EMSA) and international (regional) groupings of countries (EU, NAFTA, BSSC, etc.), constitutes in contemporary world very important and powerful regulatory mechanism of the whole shipping sector. It completes the still functioning, typical for this open, international transport sector, autonomous regulatory mechanism. The latter, however, due to commonly known weaknesses, is in fact unable to solve many nowadays emerging serious threats caused by shipping activity in global scale and problems affecting maritime transport (safety and security, social and environmental problems and many others). Consequently, it has to be supplemented by additional, public regulatory regime worked out by strong and influential international bodies.

To that group belongs primarily IMO, which plays the most important role in composing such regulatory subsystem in the world scale. The majority of conventions adopted under the auspices of IMO or for which this organization is otherwise responsible, fall into three main categories. The first group is concerned with maritime safety; the second with the prevention of marine pollution; and the third with liability and compensation, especially in relation to damage caused by pollution.[20] Outside these major groupings are a number of other conventions dealing with facilitation, tonnage measurement, unlawful acts against shipping

[15] See: Weak dollar helps push bunker prices back to record levels. Lloyd's Ship Manager, May 2008 and DiBenedetto B. Fuel burn: Rising energy costs are spurring companies to reevaluate supply chains. The Journal of Commerce Online. 18 June 2008.

[16] Kirschbaum E. Harnessing kite power to a ship. International Herald Tribune. 20 January 2008.

[17] Additional information on SkySails systems and MV Beluga SkySails can be found at http://www.skysails.info/index.php?L=1.

[18] Benamara H., Valentine V., Fugeza M., Fuel prices, transport costs and the geography of trade. Op.cit., p. 8

[19] Begerson S. G., Arctic Meltdown – The Economic and Security Implications of Global Warming. *Foreign Affairs*. March/April 2008.

[20] The full compilation of all IMO conventions and protocols amending the conventions along with their status indicating the date of entry into force, number of contracting states as well a tonnage percentage covered by each of those lawful instruments is listed on IMO website: www.imo.org/Dynamic/Search /Index.asp

and salvage, etc. Taking into account the number of the IMO regulatory instruments existing in form of conventions and protocols amending the first ones, as well as number of contracting parties (countries) and the percentage of world tonnage covered by each of those legal instruments, it may be claimed that this organization creates a real global shipping policy constituting the backbone of the world maritime transport regulatory mechanism.

In addition to IMO, in formation the widely understood economic, social, technical and environmental order in the world shipping industry participates ILO, too. It prepares conventions and recommendations concerning regulation of social standards in maritime sector. The organization has set out many minimum requirements for decent work in the maritime industry. Recently, in 2006, ILO has adopted a new consolidated Convention (C 186) that provides a comprehensive labor charter for the world's 1.2 million or even more seafarers, addressing the evolving realities and needs of a sector that handles 90 per cent of the world's trade.[21]

The new ILO's Maritime Labor Convention, 2006 clearly sets out a seafarers' "bill of rights". Its provisions will help to meet the demand for quality shipping, which is crucial to the global economy. The convention will apply to all ships engaged in commercial activities with the exception of fishing vessels. The new Convention consolidates and updates 68 existing ILO maritime conventions and recommendations adopted since 1920, among them convention 147 of 1976 /*Merchant Shipping (Minimum Standards) Convention*, convention C165 (1987), C178 and C180 of 1996, simultaneously enforcing revision of 37 other ILO's conventions.[22]

The new convention is designed to encourage compliance by operators and owners of ships and strengthen enforcement of standards at all levels, including provisions for onboard and onshore complaint procedures for seafarers regarding the shipowners' and shipmasters' supervision of conditions on their ships, the flag States' jurisdiction and control over their ships.

The Convention sets minimum requirements for seafarers to work on a ship and contains provisions on conditions of employment, hours of work and rest, accommodation, recreational facilities, food and catering, health protection, medical care, welfare and social security protection.

Under the new convention, ships that are larger than 500 GT and engaged in international voyages or voyages between foreign ports will be required to carry a "Maritime Labor Certificate" and a "Declaration of Maritime Labor Compliance". The Declaration sets out shipowners' plans for ensuring that applicable national laws, regulations or other measures required to implement the Convention are complied with on an ongoing basis. Shipmasters will then be responsible for carrying out the ship-owners' stated plans and keeping proper records to provide evidence of compliance with the convention. The flag State will review the shipowners' plans and verify and certify that they are in place and being implemented. This will put pressure on shipowners that disregard the law, but will remove pressure from those that comply.

Discussing international maritime transport policy, it should be noticed that EU is strongly committed in setting-up such regulatory mechanism and not only within the Community. The European Commission's transport policy aims at the harmonious performance of the European maritime transport system as a whole. It has performed at once two strategic goals. Over the years, the Commission has built a quite comprehensive regulatory framework encouraging the efficiency of ports and maritime transport services, *inter alia* reinforcing market position of EU fleet flying member states' flags and strengthening competitive advantages for EU shipowners in benefit of all other economic sectors and of the final consumers on one hand and safety as well as security in shipping activities on the other. The Commission supports actively the efforts of the EU member states to promote a European merchant fleet offering quality shipping services in Europe and, what is important, all over the world. The Commission is also promoting short sea connections between all the maritime regions of the European continent, as this transport mode represents an opportunity to solve road congestion problems while reducing significantly the environmental impact of the overall transport and supply chains. Thanks to the Commission's decisive action, Europe is protected today with very strict safety rules preventing sub-standard shipping and reducing the risk of environmental catastrophes (i.e. strict requirements for double hull tankers, accelerating phasing-out single-hull tankers, etc). The recent EU actions and regulations concerning maritime safety will, hopefully limit the number of the maritime accidents. The packages Erika I, Erika II or the newest third package of maritime safety measures should yield gradual but significant improvement of maritime safety[23]. The Commission also works actively against piracy and terrorism threats. Other important field of activity of the EC concerns the social dimension, looking after working conditions, health and safety issues and professional qualifications of seafarers. Finally, the EC works for the protection of citizens as users of maritime transport services, ensuring safe and secure conditions, looking after their passengers rights and examining the adequacy of the public service maritime transport connections proposed by EU member states. Last but not least, due to the growing environmental constraints, maritime transport is also regarded in the EU as the potential area of the internalization of external costs its generates in the global scale. Admittedly,

[21] www.namma.org/resources/iloNewCharter2006.htm

[22] Countries that do not ratify the new Convention will remain bound by the previous Conventions that they have ratified, although those instruments will be closed to further ratification.

[23] 2006. *Maritime Transport Policy.* European Commission.

it participate in total sum of external costs at relatively low level, but some cost categories relating to air pollution (SO_x, NO_x, etc.) and ships' accidents (mainly oil spills) regarding as typical maritime externalities amount to quite significant sums in global scale. Due to that, in close cooperation with IMO, EC intends within the EU's sustainable maritime transport policy to include this sector into its regulatory framework concerning internalization of external costs.[24] In case of accomplishing that objective, it would be the deeper every known form of public intervention into the real sphere of international maritime transport.

3 CONCLUSIONS

Currently functioning maritime transport regulatory system with its typical dual mechanism interacting international shipping's real sphere, strongly affects both operational sphere and development of maritime transport in global scale. There are widely seen numerous global effects of its regulatory activity, such as:

1. creation of international order in this transport sector based on common, widely accepted international standards relating to technical, operational, economic, social and environmental aspects,
2. growing safety and security at sea as well as security of maritime supply chains; it means, that shipping is getting less risky and more reliable as a mode of transport, strongly supporting the development of seaborne trade,
3. enhancing intermodal competitiveness of maritime transport operators, especially against road haulage carriers by promoting short sea shipping, development of intermodal transport and new concepts of logistics supply chain management. Consequently, maritime transport will be stronger committed in accomplishment widely promoted strategy of sustainable development (EC concept of Greener Transport),
4. increase in maritime transport operational productivity which should bring about its higher efficiency and effectiveness in term of time and costs of handling seaborne trade,
5. encouraging technical and technological progress in shipping industry as well as widely perceived innovation; among others in the area of the fleet operation and management (logistics concepts),
6. reduction of vessels' life cycles in purely technical and economic terms, speeding up implementation of digressive methods of ships depreciation,
7. growing purchasing costs of new tonnage as well as exploitation costs of the existing fleet (results of necessary technical conformity), which will undoubtedly strengthen the competitiveness in maritime transport and subsequently the pressure towards further capital concentration both vertical and horizontal in this transport sector.

The existing (dual) regulatory mechanism in shipping sector, consisting of two in their nature different subsystems, needs to be internally coherent and not self-contradictory. As a result of growing international public regulation (safety and security reasons), maritime transport sector is getting more international even in that sense that its globally dispersed markets become more international and unified. Consequently, autonomous regulatory subsystem in maritime transport becomes more homogenous and coherent as well. The process of relatively extensive pervading public regulatory mechanism into autonomous one will have to last as long as freight markets being under the growing pressure of international maritime transport policy wholly accumulate and in the end incorporate main objectives of public regulation. It may abide very long, being determined to some extent by the development of commodity markets (primary ones).

[24] Greening Transport. COM(2008)433 final. Brussels. 8.7.2008

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14.2
Maritime safety in European concept of the internalization of external costs of transport

M. Matczak
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: Efficient and effective transport system is the key element for the future development of European economy. Simultaneously, the process of transport development is connected also with the negative effects for environment and society. For that reason, the concept of internalization of all external costs of transport is developing in European Union. The concept characteristics and specificity in the maritime transport is the main issue of the following analysis. The special interest is focused on the maritime safety, one of the key external cost category.

1 CONCEPT OF THE TRANSPORT EXTERNAL COSTS INTERNALIZATION

1.1 *Definition and characteristic of the external costs of transport*

The transport sector have today a significant importance in global economy and development. Bring the people closer together, help in the production and service activity. Simultaneously, is itself the crucial part of economy. In Europe, is responsible for 10% of European gross domestic product and employs about 10 million people (2001. *White Paper. European transport Policy for 2010: time to decide.* European Commission). Despite the whole positive influence on the global economy and society, transport is also the source of unwelcome effects. Unfortunately, only the part of that negative influence is bore by the transport providers (private costs). Huge amount that effects, called 'external' is burdening of society, environment of national budgets. The current methodology of calculation is making possible a financial expression of these effects – external costs of transport. What is more, these costs are not borne by the transport users and hence not taken into account when they make a transport decision (2008. *Handbook on estimation of external costs In the transport sector.* Delft, Netherlands).

The most important categories of the external costs of transport are:

- transport congestion (infrastructure scarcity);
- accidents;
- air pollution;
- noise;
- impacts on climate change;
- nature and landscape;
- water and soil pollution;
- costs in sensitive areas;
- up- and downstream;
- urban effects;
- costs of energy dependency.

The costs of *congestion* could be reflected by: travel time increases, vehicle provision and operating costs, disamenities in crowded system, additional fuel costs reliability, scarcity of slots. In case of *accidents costs* the external part is connected with the part of costs are not covered by risk oriented insurance premiums, like: material damages, administrative costs, medical costs, production losses and the so called risk-value as a proxy to estimate pain, grief and suffering in monetary values. *Air pollution* is the next kind of costs, reflected mostly by health costs, building and material damages, crop losses in agriculture and impacts on the biosphere or impact on biodiversity and ecosystems. *Noise* is also important negative effect of transport activity. Its level could be estimated on the basis of costs of annoyance or health costs (hearing damages or nervous stress reaction). The key areas of *climate change* costs assessment are sea level rise (additional protection), energy use (heating), agriculture impacts (crops changes), water supply, health impact (heat or cold stress), ecosystems and biodiversity (extinction of vulnerable species). The following sorts of external costs are regarded as the less important and more difficult to estimate. *Nature and landscape* effects influencing on habitat loss, habitat fragmentation or habitat quality loss. The *water and soil pollution* are connected with the repair costs or health costs for human beings. The indication of *sensitive areas* external costs is caused by higher environmental pressure in that places and taking into consideration the all kinds and types of costs. The *up- and downstream* costs are generated in the other areas of economy by there are caused by transport development (energy production, vehicle production, infrastructure construction). The next sort of external costs – *urban effects* are made by other participants of motorized traffic on the urban areas (pedestrians,

Table 1. Total external costs (excluding congestion) by cost category and transport mode in 2000 (million Euro per year).

	Road	Rail	Air	In. navig.	Total
Accidents	155,588	262	590	0	156,439
Noise	40,410	2,136	3,098	0	45,644
Air pollution	164,282	4,447	4,235	1,652	174,617
Climate change	112,383	2,894	79,931	506	195,714
Nature & landscape	18,359	266	1,298	91	20,014
Up/Downstream	43,483	1,748	1,762	383	47,376
Urban effects	9,909	563	0	0	10,472
Total (EU 17)	544,415	12,315	90,914	2,632	650,275
%	83.7%	1.9%	14.0%	0.4%	100%

Source: 2004. *External costs of transport. Update study.* Summary. INFRAS, Zurich/Karlsruhe, October.

cyclists, etc.). They are mostly regarded as time losses or scarcity problems. The last sort of external costs is the *energy dependency* resulted from the unequal distribution of energy sources. For that reason, the costs due to transfer of wealth, potential GDP losses or macroeconomic adjustments costs could be foreseen.

According to the estimation the EU financial losses connected with the environmental or congestion problems are indicated on the level of 1% of EU gross domestic product each (2006. *Keep Europe moving – Sustainable mobility for our continent.* European Commission). The important issue is also the modal and structure of the transport external costs category (Table 1).

The most important sort of external costs, responsible for about 30% of total sum is climate changes. The following position are occupied by air pollution (27%) and accidents costs (24%). The next kinds of external costs have only about 7-5% of total share. Two third of total cost is connected with the passenger transport (private passenger cars). The modal comparing indicates on the leading role of road transport (83.7%). For that reason the road traffic is the best reconnoiter mode of transport in the aspect of external costs.

1.2 *The concept of internalization of the external costs of transport*

The internalization concept is based on the assumption, that, external effects should also be taken into consideration in the decision making process. It is connected with the rapid growth of global transport and increasing role of external, negative effects which are produced.

These initiative has been presented in the European Union documents for years (e.g. Green Book (1995), White Papers (1998, 2001, 2006)).

The aims of implementation of the external costs internalization are defined like, the following:

– Improvement of transport efficiency, both economical and environmental (use of infrastructure and rolling stock);
– Guarantee fairness between transport modes (fair price considering);
– Improve safety and reduce environmental nuisances of transport.

According to the European concept, the most efficient way of internalization is the proper regulation of the transport activity. The market - based instruments, like taxes, charges, emission trading should be used. In accordance with the theory assumption, the calculation should be based on the marginal costs.

The most important challenge is the detailed estimation of the regulation (financial burden) level. The two main approaches to the marginal external costs estimation are indicated in the literature: *bottom-up* or *top-down approach*. In first case, the calculation is based on the specific case studies. These approach could bring the detailed outcomes but it is costly and difficult to generate. On the other hand (*top-down approach*), the total value of external costs is divided between particular modes. The differentiation of traffic condition or stock categories make the method very imprecise (2008. M. Bąk, B. Pawłowska: *kalkulacja kosztów zewnętrznych transportu – krok naprzód w polityce Unii Europejskiej.* Materiały konferencyjne, EuroLog 2008, Warszawa).

Despite the advanced works on the methodology of external costs calculation, it is difficult to recapitulate that the 'system' is ready for implementation. It is still very complicated and difficult for the transport practice. What is more important, there no exist the proper 'political climate' for implementation. On the one hand, the transport companies and users will protest against the increasing burden of service activity (especially road haulers), on the other the financial crisis is additionally postponing the potential date of start. It is crucial, that there no exists reliable analysis of the influence of internalization on the functioning of the European transport market.

2 THE EXTERNAL COSTS OF MARITIME TRANSPORT

2.1 *Crucial aspects of maritime transport external costs calculation*

The external costs of maritime transport are the most poorly recognized category among the transport modes. There exist several reasons of that situation.

First is the international character of maritime traffic, separated from the land areas. Thanks that, maritime traffic have limited influence on society and its activities (spatial separation). The next reason is restricted scope of maritime infrastructure problems and its relatively high capacity (observed only in case of particular seaports, straits or canals). The other incentive of low importance of maritime traffic in the internalization concept is the relatively low level of generated costs. The crucial aspect of the maritime traffic analysis is also discrepancy between infrastructure and shipping in the light of external costs characteristics.

Table 2. Accidents costs in maritime shipping in selected European countries in 1998 (million €).

	External accidents costs	Internal accidents costs
Finland	0.5	91
Greek	30	37
Italy	0.5	5
Sweden	6	75
Spain	15	236
Netherlands	1	4

Source: 2003. UNITE. Deliverable 8&12.

Simultaneously, the essential problem in the analysis process is the limited access to the detailed and proper data concern the maritime traffic.

Despite the problems indicated above, all costs categories in maritime transport could be indicated and calculated. For the simplification of the analysis the scope of interest is limited to the accidents costs resulted from maritime shipping activity.

2.2 *Maritime accident external costs in the internalization process*

The estimation of the maritime accident costs needs the detailed indication of the most important categories of the effects. It is caused by the much more complicated nature of sea accidents than in other mode of transport. The main difference is the appearance of couple of cost categories caused by the occurrence. The following cost categories could be observed:

- Costs of damage to ships;
- Costs of damage to infrastructure;
- Costs resulting from human injury and death;
- Environmental damages (e.g. pollutions, nature and landscape costs);
- Operational damages (e.g. sunken vessels blocking the waterway);
- Administrative costs (2001. *UNITE*. P. van Donselaar, H. Carmighelt. Workpackage 5/8/9., s. 40).

It is extremely difficult to present complete analysis of the external accidents cost of maritime traffic. However, there is some data reflected this issue (Table 2).

It could be stated that the part of about 10.6% is the external costs of maritime accidents. That is mean they are 'covered' by environment or society. The following part are the private one. The most important are human injury or death and of course environmental damages.

The problem of the value of human health or life is one of the basic in the external costs concept. It is extremely difficult to express the life's value in financial category, therefore the theory call these kind of costs like 'value of casualties avoided'. The table 3 present the accessible outcomes of the studying issue.

The average value of fatality avoidance is counted on 1.3 m Euro, severe injury 177.1 thou. Euro and slight injury 13.1 thou. Euro.

Table 3. Estimated values for casualties avoided in transport (thou. €2002).

Country	Fatality	Severe injury	Slight injury
Austria	1 760,0	240,3	19,0
Belgium	1 639,0	249,0	16,0
Cyprus	704,0	92,9	6,8
Czech republic	495,0	67,1	4,8
Denmark	2 200,0	272,3	21,3
Estonia	352,0	46,5	3,4
Finland	1 738,0	230,6	17,3
France	1 617,0	225,8	17,0
Germany	1 661,0	229,4	18,6
Greece	836,0	109,5	8,4
Hungary	440,0	59,0	4,3
Ireland	2 134,0	270,1	20,7
Italy	1 430,0	183,7	14,1
Latvia	275,0	36,7	2,7
Lithuania	275,0	38,0	2,7
Luxembourg	2 332,0	363,7	21,9
Malta	1 001,0	127,8	9,5
Netherlands	1 782,0	236,6	19,0
Norway	2 893,0	406,0	29,1
Poland	341,0	46,5	3,3
Portugal	803,0	107,4	7,4
Slovakia	308,0	42,1	3,0
Slovenia	759,0	99,0	7,3
Spain	1 122,0	138,9	10,5
Sweden	1 870,0	273,3	19,7
Switzerland	2 574,0	353,8	27,1
United Kingdom	1 815,0	235,1	18,6
Ave.	1 302,1	177,1	13,1

Source: 2008. Handbook on estimation of external costs In the transport sector. Delft, Netherlands.

The analysis of these costs structure indicates that the total premium paid by insurance companies amounts to 50% of the injury and death costs for victims (Calculation for inland navigation. 2001. *UNITE*. P. van Donselaar, H. Carmighelt. Workpackage 5/8/9., s. 42). Therefore, the half of the cost could be indicated like 'external'. Looking into maritime statistics, the average annual number of fatalities at sea accounts for 608 (based on the period 1989 – 2004) (2005. *Casualty statistics and investigations*. Annex 2. IMO, London 23 February). It could be resumed, that the annual external accidents cost referring to human life in the maritime transport is about 3.95 billion Euro.

The second type of external effects caused by maritime accidents are environmental damages. The various categories of costs could be indicated with correspondence to environment. There are: pollutions, nature and landscape costs, costs in sensitive area, etc. In maritime practice, the following kinds of costs are defined:

- Natural Resource Damage Costs (NRDA), which are based on estimated costs to restore equivalent resources and/or ecological services.
- Socioeconomic costs including damages to real and personal property, loss of use of natural resources (parks and recreation areas), and loss of income and

Table 4. Selected major oil spills In Europe.

Name of ship	Year	Location	Oil lost (t)
Amoco Cadiz	1978	Off Brittany, France	223 000
Haven	1991	Genoa, Italy	144 000
Torrey Canyon	1967	Scilly Isles, UK	119 900
Irenes Serenade	1980	Navarino Bay, Greece	100 000
Urquiola	1976	La Coruna, Spain	100 000
Independienta	1979	Bosphorus, Turkey	95 000
Jakob Maersk	1975	Oporto, Portugal	88 000
Braer	1993	Shetland Islands, UK	85 000
Prestige	2002	Cape Finistere, Spain	77 000
Aegean Sea	1992	La Coruna, Spain	74 000
Sea Empress	1996	Milford Haven, UK	72 000
Erika	1999	Brittany, France	20 000

Source: 2007. *Panorama of Transport.* Edition 2007. European Commission.

Table 5. Oil spill cleanup costs in Euro.

Continent	Euro 1999/ton
North America	19,815
Latin America	3,056
Africa	3,164
Europe	10,808
South Pacific	5,699
Middle East	1,058
Asia	27,496
World Wide Average	8,073

Source: Bickel P., Sieber N., Kummer U.. 2006. *Marginal environmental costs case studies for air and water transport.* GRACE, IER, University Stuttgart., s. 34.

expenses (fishing, tourism, recreation, shipping and other commerce).

– Response costs comprise appropriate spill response operations based on procedures outlined in local contingency plans and historical case studies for mechanical-recovery operations (Bickel P., Sieber N., Kummer U.. 2006. *Marginal environmental costs case studies for air and water transport.* GRACE, IER, University Stuttgart., s. 34).

The oil spills are the most important type of sea accident. They effects influence significantly the marine environment. Unfortunately, these kind of periodical occurrences has been noticed for years (Table 4).

In case of oil spills, the negative effect on the environment is unquestionable. The part of the effects could be limited by cleanup activity (table 5), constituting the private part of social costs.

The other losses connected with the accidents are ‘covered’ by the environment and citizens.

The presented elements of the maritime accidents external costs calculation do not fulfill the whole abundance of issue. Unfortunately, there no exists the exact and complete calculation of the external environmental costs of maritime accidents. Simultaneously, it is hard to define the proper way of the internalization of these negative effects.

3 CONCLUSIONS

The concept of internalization of external costs of transport is today the crucial element of European transport policy. So far, the theory and the methodological base for the concept implication have been done. Unfortunately, the financial and economic crisis on the global markets has limited the tempo of further steps.

Maritime transport is also regarded as the potential area of the internalization. Fortunately, the share of maritime transport in total sum of external costs is marginal. The crucial cost category of maritime externalities are costs of accidents. In case of these kind of disaster the majority of external costs are borne by environment.

The current EU action and regulation concerning maritime safety will, hopefully, limited the number of the maritime accidents. The packages Erika I, Erika II or the newest third package of measures should bring the gradual improvement of maritime safety (2006. *Maritime Transport Policy.* European Commission). On the other hand, the internalization could be regarded as the positive action for maritime transport. The heavy increase of financial burden for road transport should enable the practical implementation of the old EU’ challenge, expressed in form ‘from road to sea’, stimulating, at the same time, demand for maritime transport services.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

14.3
e-Maritime: An enabling framework for knowledge transfer and innovative information services development across the waterborne transport sector

J. Graff
BMT Group Ltd., Teddington, England, UK

ABSTRACT: The economic and social impact of the waterborne sectors in Europe cannot be overstated, employing directly more than 3 million people and generating a turnover of about €250 billion representing more than 1% of the EU's GDP. In order to maintain its leadership and competitiveness, Europe must take advantage of new market opportunities and address these challenges by means of focused research, development and innovation. In recent years the impact of digital technology and relevance of geospatial information has been increasingly felt across the whole maritime community bridging waterborne and coastal activities. The challenge for the maritime and marine science communities is to accelerate the transformation of the maritime sector into one that is able to exploit market-led opportunities and create high value added outputs that fully embraces technological and scientific advances. e-Maritime offers itself as the enabling framework.

1 INTRODUCTION

In the last few years, advances in digital communication, ocean climate modelling and earth observation systems have began to have an increasing impact across the whole maritime community bridging waterborne and coastal activities.

1.1 *Environment and security*

In the waterborne sector the demands for improved navigation safety and security have introduced new ship monitoring technologies such as AIS and LRIT and stimulated demand for increased coverage and accuracy of satellite observations. Concern about pollution impact and consequence of oil spills, ballast waters and ship emissions have introduced policy driven information requirements associated with a raft of new compliance legislation arising from; MARPOL (Annexes I, VI), Ballast Waters Management Convention 2004, UK Marine Bill (UK Marine Bill 2008) and the new Integrated Maritime Policy for the European Union (EU 2007) which covers coastal protection and maritime transportation. In the context of climate change there is a growing need to have access to accurate weather and sea state (tides, currents, waves) forecasts as input to data-driven services such as oil spill monitoring, ballast waters dispersion and global ship routing. These strategic baseline data have been identified as "marine core services" under the European FP7 development programme GMES (Global Monitoring of Environment and Security) which has been ongoing since 2000.

1.2 *Marine Stewardship*

In response to the need for increasing levels of information addressing state and sustainability of the marine environment to support local, regional and national policy the concept of *Marine Stewardship* has in recent years started to take on an important new meaning and dimension (Graff 2006). Although *Marine Stewardship* has a country by country interpretation there is common emphasis on importance of the spatial data domain and a growing recognition that governance, interoperability and information services are key underpinning features. At the European scale the development of a new digitally based geospatial information philosophy is being supported under the European Commission INSPIRE (Infrastructure for Spatial Information in Europe) Directive which in turn is part of a global effort to build commonality across national "Spatial Data Infrastructures" or SDI's (Labonte et al 1998, ESDP 1999). The GMES programme addresses the provision of end user information services through integration of measurement, modelling and prediction within a geospatial systems environment. Many of these emerging services are *marine policy driven* providing information to support coastal zone governance relating to fisheries, quality of waters, extraction of gravels, protection of marine species and flood protection. In view of the emerging requirement to extend land environment mapping into coastal waters (Land-Marine Workshop 2007) and provide access to these data, efforts to define and develop the protocol and standards for a marine specific SDI are underway (Ng'ang'a 2004, Sutherland 2005, Sutherland & Nicholas 2006). The International

Hydrographic Organisation (IHO) has acknowledged the potential importance of a marine spatial data infrastructure and a special IHO workshop on *Marine SDI* was convened during the *Geomatica* 2007, to discuss related issues. The first of five resolutions agreed at the IHO Workshop states;

"IHB to communicate with IOC to cooperate on the development of the spatial data standard S-100, with a view to facilitate marine/hydrographic data exchange".

This is an important statement that recognizes the need for knowledge exchange and collaboration between the maritime technology and marine science communities to address emerging information needs increasingly relevant to development and welfare of the waterborne industry. The statement reflects earlier calls for such cross sector dialogue made by the author (Graff 2006, 2007).

This has led to formation of a new IHO Working Group on Marine Spatial Data Infrastructure (MSDIWG) which together with the strategic Working Group on Transfer Standard Maintenance and Applications Development (TSMAD-responsible for S-100 development) will provide an important contribution to evolution of the IMO *e-Navigation* vision.

1.3 *Marine transportation*

Motorways of the Sea (DGTREN 2005) is a growing concept that aims at introducing new intermodal maritime-based logistics chains which will bring about a structural change in our transport organisation that will be more sustainable and commercially more efficient. At European scale there are four proposed marine motorway systems linking regional states which are illustrated in Figure 1 and at global scale the Marine Electronic Highway pilot project (Sekimizu et al 2001, Gillespie 2005) in the Malacca Strait being progressed by IMO represents another important first step in prototyping some of these ideas.

In addition to conventional navigation aids governing weather and bathymetric charts the evolution of marine motorways will demand increasingly sophisticated products and services to monitor traffic, mitigate accidents and pollution impact and to optimise and improve commercial efficiency of routing and port turn-around. For example, AIS and LRIT are already being adopted as key data carriers to improve monitoring and safety of regional and global vessel traffic and improvements in marine broadband are leading to new types of remote monitoring and information exchange. A service offering that is receiving much attention from several developers is the concept of ship performance monitoring which integrates onboard vessel behavior parameters with prevailing sea state and weather to compute continuous updates of optimal routing advice delivered remotely to the bridge. The IMO e-navigation strategy offers a vision for a web services infrastructure that lends itself to delivery of a wide range of such new added-value marine information services in addition to mandatory ECDIS information.

Figure 1. The four proposed European Motorways of the Sea interconnecting regional sea States in Europe.

These initiatives also highlight a particularly important feature namely; the need for convergence between maritime technology and marine science in order to realise the degree of knowledge integration needed to provide the types of sophisticated maritime information services required today.

2 E-NAVIGATION

The *IMO e-Navigation Strategy* was initiated in 2005 with intent on embracing new digital technologies to provide the framework for new digital services adoption across the maritime transport community *to support navigation*. IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities) was charged by IMO with developing the e-Navigation vision and standards (IALA 2007). A definition for *e-Navigation* was agreed at the IALA e-Navigation Committee meeting (e-NAV2) in Southampton in March 2007; It reads:

"E-Navigation is the harmonised collection, integration, exchange and presentation of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment"

e-Navigation is underpinned by 7 points that have to be considered in an integrated fashion.

1 Electronic charts and weather information
2 Electronic positioning signals
3 Electronic information on vessel route, course, manoeuvring etc.
4 Transmission of positional and navigational information

5 Display of information
6 Information reporting, prioritisation and alert capability
7 Transmission of distress alerts and maritime safety information

In order to have the functionality demanded for delivery and display of mandatory navigation data, e-Navigation has to be supported by an ECDIS.

2.1 *ECDIS*

A key feature in progressing e-Navigation lies in universal adoption of *Electronic Nautical Charts* (ENC) and the availability of a common approach to the use and display of ENCs and related navigation aid data onboard vessels namely, the *Electronic Chart Data Information System* or ECDIS. In July 2008 draft regulations were presented by IMO to make the carriage of ECDIS a mandatory requirement under SOLAS Chapter V Safety of Navigation. It is anticipated that this will be adopted and thus trigger the universality of ENC adoption and usage.

The role of ECDIS is especially important in view that a new version (S-100) for the digital code structure of ENC's (commonly known as S-57) has been developed (Alexander et al 2008) and is currently being released under test with adoption envisaged in the next few years. The new code is "open standards compliant" which enables the handling of many other data types, for example, S-100 will support gridded and time series (x, y, z, t) data in support of dynamic ECDIS, marine GIS and web based services. This paves the way for a new generation of ECDIS systems that can exchange data with coastal GIS databases and operational forecasting centres and provide a gateway for other decision-support information services.

However, it also raises questions regarding scope and definition of ECDIS and what influence IHO might have on commercial services development through Working Groups TSMAD and MDSIWG.

3 E-MARITIME

Although conceived to improve the safety and security, e-Navigation also has a potential to increase efficiency and performance of ship operations, which is the main consideration for ship-owners, operators and their service providers e.g., minimise fuel consumption and mitigate emissions.

In 2006 the EC started considering e-Navigation in parallel with IALA and tasked the FP6 MarNIS (Maritime Navigation Information Services) project with developing an e-Navigation vision. The MarNIS e-Navigation Task Force meeting (Oslo, 18.09.2006) revised the concept of e-Navigation to embrace the following criteria:

- to minimise navigational errors, incidents and accidents;
- to protect people, the marine environment and resources;

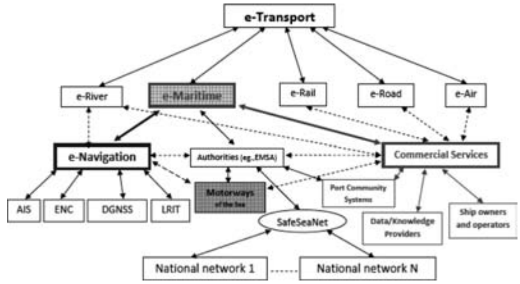

Figure 2. e-Maritime and e-Navigation shown in the broader context of e-Transport information services provision.

- to improve security;
- to reduce costs for shipping and coastal states; and
- to deliver benefits for the commercial shipping industry

The last two points extend *e-Navigation* into a *system* termed *e-Maritime*. This is important and provides a clear distinction between the two namely.

e-Navigation (protocol oriented) is to ensure provision of navigational data and information, also from/to Aids to Navigation etc., in a standardised/harmonised way to facilitate common interpretation of said navigational data and information.

e-Maritime (system oriented) is the promotion of the use of all maritime data and information, and the distribution thereof, to facilitate maritime transport and provide value added services to improve the profitability of shipping.

The aim of *e-Maritime* is to deliver benefits to the public, transport consumers, public authorities and the maritime community, by means of ICT and to offer a *framework for commercial services*.

A schematic of the e-Transport overview showing both e-Navigation and e-Maritime components is presented as Figure 2 adapted from work by one of e-Navigation's pioneers Dan Pillich (Pillich 2007).

The diagram highlights the role and the complimentarity of e-Maritime as an important overarching framework that brings together a diversity of technologies to enable Motorways of the Seas, namely waterborne transport, with the benefit of latest advances in ICT and marine science knowledge.

However, as has already been noted under 2.1 above, it is not yet clear what the IMO vision framework for e-Navigation will embrace and where conflicts with commercially driven e-Maritime services will arise.

4 INTEGRATION AND INNOVATION

The EurOcean 2007 conference produced the "Aberdeen Declaration", calling for an integrated European Marine and Maritime Science, Research, Technology and Innovation Strategy which should enable:

- foresight activities to identify new and emerging scientific challenges and opportunities;

- cross-sectoral, multinational and interdisciplinary research partnerships;
- co-operation between research, industry and other stakeholders to enhance knowledge and technology transfer and innovation;
- development of scientific and technology capacity to strengthen the knowledge economy;
- shared use, planning and investment of critical infrastructure on a Europe-wide basis.

This stirred considerable interest and support at European level and a *Post Aberdeen Task Force* was established made up of representatives from Marine Science and Maritime Industry interest groups including ICES, ESF Marine Board, ETP Waterborne and EuroGOOS. This was deemed relevant as a vehicle for providing a *representative response* from the European marine and maritime communities to the EC actions calling for initiatives to demonstrate science and technology crossover and innovation.

From a personal perspective, I would argue that the representation on the *Task Force* is far too heavily marine science research biased with the WATERBORNE consortia representing industry, having a shipbuilding focus. Consequently, there is a gap in the key new crossover area that is framed in e-Science (Hey & Trefethen 2003, Env e-Science 2008) and ICT technology applications, *namely e-Maritime*, that are enabling a dramatically new data-driven approach to marine science and technology.

Curiously, there is little or no recognition in the current EC discourse on European maritime strategy of the emergence of e-Maritime, or indeed e-Science, as an important enabler of new information services and driver for innovation and integration across marine science and maritime technology research outputs. Why?

Perhaps the answer lies in some of the prophetic key recommendations identified more than a decade ago in the seminal UK Marine Foresight Panel study 1994–97 report (UK Marine Foresight 1997) chaired under the late David Goodrich namely;

4.1 *High priority areas for wealth generation*

Information Technology: For acquisition and processing of increasingly large volumes of data, the development of intelligent information systems and GIS-based data management systems is needed, linking satellite remote sensing, GPS navigation, monitoring networks (data buoys, commercial vessels) and hazard databases. Also required is development of a marine information service backed by data acquisition.

4.2 *Actions for implementation*

- The opportunities to apply **Digital Information Technology** to the marine environment are many and varied. Industry should lead this initiative in consultation with academia and government. The Panel recommend the setting up of a user led interest group and a LINK programme for the application of Digital Information Technology to the marine environment."

5 CONCLUSION

It is eminently clear that digital information technology is driving a whole new agenda for change in the waterborne sector and we are at the onset of seeing a new industry emerge designing and delivering innovative marine information products and services.

This offers challenge and opportunity but demands integration and innovation across marine science and marine technology sectors and uptake of new enabling technologies such as e-Science. The new enabling framework for marine informatics is proposed as *e-Maritime.*

Awareness of the underpinning technologies defining e-Science and e-Maritime and understanding their innovative integration potential seems to be lacking across marine and maritime communities. This has to be remedied urgently if Europe is to become a player in the emerging global information services market. Europe has the potential to lead.

Finally, I would reiterate, now ten years on, a single recommendation adapted from the 1997 UK Marine Foresight Panel report namely;

- The opportunities to apply **Digital Information Technology** to the marine environment are many and varied. Industry should lead this initiative in consultation with academia and government. I recommend the setting up of a user led interest group for the application of Digital Information Technology to the marine environment under the aegis of *e-Maritime*.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

14.4 Challenges for Polish seaports' development in the light of globalisation processes in maritime transport

A. Przybyłowski
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: Ports operations become more capital intensive, labour saving and space consuming. Due to globalization processes and liberalization of the EU transport markets the seaports are under the huge competitive pressure put mainly by container transport operators committed in the logistic transport chains. Polish seaports have difficulties in facing such a competitive environment.

1 INTRODUCTION

Polish seaports, like all ports in the world, are being confronted by forces of change and uncertainty that are reducing their abilities to control their own destinies. Since several years, other actors in the transportation industry (the shipping lines in particular) are shaping port development. They have been put 'at mercy' of the shipping alliances dominating world trade not only on water, but also on land. Moreover, the process of deregulation in the common transport policy in the EU enables shaping equity mergers and alliances on land. For instance, the rationalisation of rail services raises the potential of differential access to ports. Most port authorities play only a secondary role in the global game. More than ever before, as intermediate points in transport chains, linking shipping with road and rail modes, ports are vulnerable to developments on both land and water. These developments have brought about uncertainty and change that has made port planning extremely difficult.

2 GLOBALISATION AND INTEGRATION IN THE MARITIME TRANSPORT

Seaports' development is influenced by many factors. Especially, the globalisation and integration processes affect the evolution of their management systems and models. Vertically integrating transport chains make seaports vulnerable to rapidly changing contemporary environment.

The coastline of the European Union is many thousands of kilometres in length and contains well over 600 individual ports. These handle around 90% of EU external trade and more than 35% of trade between EU countries. This involves handling 3.5 billion tonnes of goods and 350 million passengers being transported on millions of ship journeys each year (www.emsa.europa.eu/end, 25.02.2007). The ongoing process of cargo flows concentration benefits to the biggest EU ports, mostly in the northern part of the continent. A big part of the increase over the years can be attributed to the increase of import of oil and oil products (http://epp.eurostat.cec.eu.int, 25.02.2007).

European ports, like all ports in the world, are being confronted by forces of change and uncertainty that are reducing their abilities to control their own destinies. Since several years, other actors in the transportation industry (the shipping lines in particular) are shaping port development. More than ever before, as intermediate points in transport chains, linking shipping with road and rail modes, ports are vulnerable to developments on both land and water. These developments have brought about uncertainty and change that has made port planning extremely difficult. Interport competition has been heightened in unanticipated ways (Slack 2001).

Shipping, being the most important mode of transport in terms of volume, gets an important support from the EU. In fact, the common transport policy favours the development of environmental friendly modes of transport in compliance with the idea of sustainable development (Lisbon and Goeteborg Strategy). The EU, through a set of political actions, legal and financial instruments, promotes intermodal transport (Marco Polo Program) and creation of motorways of the seas, for instance.

Furthermore, as a result of its geography, its history and the effects of globalisation, maritime transport will continue to be the most important transport mode in developing EU trade for the foreseeable future (Maritime transport 2006). The Green Paper on a Future Maritime Policy for the European Union launched a broad debate on the development of an overall maritime policy which combines an integrated, cross-sector analysis with effective policy co-ordination and common action. According to the Commission, such a policy should combine the competitiveness and employment objectives of the Lisbon agenda with improving the health of the marine environment (EC Commission 2006).

The Blue Paper reflects the outcome of a one year consultation period launched with the adoption of the Green Paper. The results of that consultation have been brought together in a separate communication which was also published. The Maritime Policy "Blue Paper" sets out a comprehensive action plan including the Port Policy Communication which was published on 18 October 2007. The Commission identified the Blue Paper as a crucial first step for Europe's oceans and seas towards unlocking its potential and towards facing the challenges of a Maritime Europe. It should also allow the EU to make the most of its maritime assets and it will help Europe face some of the major challenges before it. The Blue Paper identifies five areas of action necessary to launch an integrated Maritime Policy for the European Union: sustainable use of oceans and seas, knowledge and innovation, quality life in coastal regions, European leadership in international maritime affairs and, finally, visibility of maritime Europe and its heritage.

These areas are translated in a concrete action plan which accompanies the Blue Paper. Key actions include the development of a European Maritime Transport Space without barriers, a White Paper on maritime transport strategy, a roadmap towards maritime spatial planning, a strategy to mitigate the effects of climate change on coastal regions, reduction of CO_2 emissions and pollution by shipping (including promotion of shore-side electricity in EU ports), sustainable maritime tourism and a European network of maritime clusters (http://www.espo.be, 2008).

The ongoing growth of the world economy in terms of GDP and industrial output accelerates the growth of the international trade and as a consequence boosts the increase of the world seaborne trade (UNCTAD 2005). According to WTO calculations, it accounts for more than 80% of the world total trade in tonnage terms. The growth rates of the seaborne trade were especially high in the recent twenty years of the 20th century. In 2004 it reached 6,76 billion tones of loaded goods. The annual growth rate reached 4.3% over that of 2003, and the increase of the world merchandise exports volume was 13% higher at that time. The world merchant fleet grew in deadweight tons (dwt) up to ca 900 million that represents 4.5% increase. This tendency is still going on and especially the number of containerships grew by 15.5% (see tab. 1). The rapid increase of the world seaborne trade boosts the development of the maritime transport. As a result, it accounts nowadays ca. 90% of the world transport in ton-miles. As a consequence the total throughput of the world sea ports has been growing considerably, reaching (according to the provisional data) more than 14 billion tones (loaded and unloaded) (Grzelakowski & Przybylowski 2006).

Containerisation that has given shipping lines greater freedom to serve markets from a wider choice of ports, thanks to so-called transferability (Fleming et al. 1994), deepened the globalisation process. Ports have no longer control over inland markets and can not be sure of the trade even in their own local areas. They have to invest huge sums of money in superstructure and infrastructure to participate in the container industry. However, it is not a guarantee to take profits from this business as some of them, despite having a container terminal, may be bypassed because of the reasons linked to the whole transportation chain, like hinterland connections. The shipping lines, being the most important players in the logistics chains, widen their maritime services and extend control over landward movements. They certainly do not take into consideration the specific merits of a particular port, but the economies of scale and conditions of the entire chain. For instance, services in the Mediterranean have concentrated in southern entirely new pivot ports, such as Gioia Tauro and Algeciras, bypassing direct services with northern reputed ports as Livorno and Marseilles. Thus, port operations can be compared to a lottery (Slack 1993). Actually, the most dynamic increase of the handled volume of the biggest EU ports concerns the container traffic. There is a high level of correlation between the EU ports development and their container handling volume. On the list of top 20 container terminals only three EU ports are named, i.e. Rotterdam, Hamburg and Antwerp, ranked 7, 9, 11 respectively. However, the percentage change of container throughput in the EU container terminals is above the world average level. In the Baltic Sea Region the level of containerization is unfortunately the lowest in Poland

Table 1. World fleet structure by type vessel in 2005–2007 (DWT $\times$ 100).

Principal types	2005	2006	2007	Percentage change 2007/2006
Oil tankers	336 156	354 219	382 975	8.1
	37.5	*36.9*	*36.7*	*-0.2*
Bulk carriers	320 584	345 924	367 542	6.2
	35.8	*36.0*	*35.3*	*-0.7*
Ore/bulk/oil	9 695	7 817	5 614	-28.2
	1.1	*0.8*	*0.5*	*-0.3*
Ore/bulk	310 889	338 107	361 928	7.0
	34.7	*35.2*	*34.7*	*-0.5*
General cargo ships	92 048	96 218	100 934	4.9
	10.3	*10.0*	*9.7*	*-0.4*
Containerships	98 064	111 095	128 321	15.5
	10.9	*11.6*	*12.3*	*0.7*
Other types of ships	48 991	52 508	62 554	19.1
	5.5	*5.5*	*6.0*	*0.5*
Liquefied gas carriers	22 546	24 226	26 915	11.1
	2.5	*2.5*	*2.6*	*0.1*
Chemical tankers	8 290	8 919	8 823	-1.1
	0.9	*0.9*	*0.8*	*-0.1*
Miscellaneous tankers	1 001	1 261	1 168	-7.4
	0.1	*0.1*	*0.1*	*0.0*
Ferries and passenger ships	5 589	5 649	5 754	1.9
	0.6	*0.6*	*0.6*	*0.0*
Other	11 565	12 453	19 894	59.8
	1.3	*1.1*	*1.9*	*0.8*
World total	895 843	959 964	1 042 328	8.6
	100.0	*100.0*	*100.0*	

Source: Complied by UNCAD secretariat on the basis of data supplied by Lloyd's Register – Fairplay 2008.

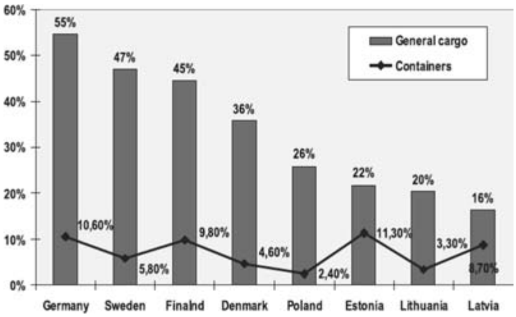

Figure 1. Level of containerisation in external trade of the Baltic Sea Region countries.
Source: M. Matczak, The Baltic Container Outlook 2007, Actia Forum, p. 26.

(see fig. 1). However the latest investments in the seaports of Gdansk and Gdynia should increases their competitiveness.

The changes in the maritime transport sector concern not only the growing volume of commodity flows and the structure, but also ships' size, specialisation, containerisation and transport chain organisation. The growing ships' size involve huge capital expenditures in ports. They refer to extensive dredging, much more dockside and handling capacity, for example. However, such an anticipation may be a risky undertaking, as there is an uncertainty over the ultimate vessels' size. As far as the organization of the maritime transport is concerned, some forms of cooperation such as strategic alliances (SAs) and equity merger and acquisition activities (M&As) have been developed. They refer mainly to the international container transport – Hanjin/Senator, P&O Nedlloyd, Hamburg-South-Group, etc.

The main result of the capital integration and other forms of cooperation is enhancing the competitive position by improving learning capabilities and the timely access to technological knowledge and also vertical integration, control of intermodal and logistic cycles and logistics outsourcing, as well. Thus, the transport of goods by sea costs have been decreasing and the effectiveness of the international combined transport chains is steadily growing. This process is still going on, despite huge unavoidable ports investments (Grzelakowski & Przybylowski 2006).

Major shipping lines formed strategic alliances because of the pressures of globalisation requiring to be present in all the major markets of the world. As a result, formerly separate services of members are being integrated and create new service configurations that ports are unable to predict the outcome. Meanwhile, ports operations become more capital intensive, labour saving and space consuming. Due to liberalization of the EU transport markets the seaports are under the huge competitive pressure put mainly by container transport operators committed in the logistic transport chains. Not all of them are able to face such a competitive environment.

The adjustment to the above mentioned globalization processes needs huge additional public investment in port infrastructure and lowering of the operational handling costs. Only the biggest terminals and port handling operators can meet those challenges and requirements set by the growing competitive environment (pressures from container operators, liners). Due to the relatively low port tariffs ports are unable to increase their income. Therefore, they need to apply for a huge public money and the access to the capital of parties involved in the multimodal transport chain. However, such a strategy is very often connected with the change of their contemporary role in a transport chain and the evolution of their model of administration and management, in particular. The Polish ports should consider specific approaches depending on the environment they are operating in to face the ongoing challenges.

3 STRATEGIES FOR POLISH SEAPORTS DEVELOPMENT

In 2005, one of the Polish Gdynia Port container terminals has been taken over by Hutchison Port Holdings Group (HPH). HPH handled that year 51,8 mln TEU on 251 quays in 43 ports. This global operator has shares on the terminals in 21 countries all over the world: in Asia, Africa, both Americas and Europe. In Europe, they are present in Belgium, Germany, Spain, the Netherlands and Great Britain. This example reflects the abovementioned globalisation and integration processes.

The existing traditional seaport administration and management systems as well as port policy objectives and requirements, based principally on the concept of exclusively port-oriented management forms in Polish ports, do not comply any more with the new logistic management challenges and growing competitive transport environment. The traditional concepts and models of national seaport policy are being steadily evolved, getting much more global and transport chain oriented. Polish seaport authorities, confronted with the abovementioned processes, must adopt efficient survival strategies in order to resist global and integration pressures. Slack mentions two possible reactions that could be adopted by seaports: keeping pace with market demands or pursuing customer-driven strategies. Porter and Robinson studies suggest providing superior value-delivery to targeted customers at a cost that provides acceptable profit levels.

The first strategy consists on carrying out expensive investments in superstructure and infrastructure in order to keep pace with shipping lines expenses on larger vessels. The second one is a response to concrete demands coming from shipping line clients. Certainly, investing huge money is not a guarantee of success and may not be even economically and economically sustainable. The third approach requires important adjustments in ports functions to fit better into local, regional and global markets (concentration on passenger business or container feeder port role, f. ex.). This solution could be a good idea for Polish ports as their participation in the container market is relatively low.

A port authority may be not only a port operator but also a land developer. Sites that have no more a port-use character can serve for urban redevelopment. Such an alternate use of port sites may bring a lot of income, because waterfront land is of a great value (Slack 2001). As mentioned above, the necessary step is a full integration of those entities into the transport chains. Such a process has already started. It is performed by horizontal and vertical forms of integration. The first one is caused by the ongoing process of privatisation of the ports terminals, mainly container ones. The global container operators, like HPH, take over container terminals becoming their owners in the world scale. The reason of this is an increasing rentability of port container terminal companies. According to Drewry Shipping Consultants, the leading container operators like HPH, CSX WT, PSA Corp., ICTSI and P&O Ports reach turnover rentability of 33%, 29%, 25%, 18,8% and 17,4% respectively. The vertical integration is based on capital concentration among the ports terminal companies and other logistic transport operators such as global container alliances (Maersk).

Till now, the ports behaved passively being taken over by other operators players/ carriers. Thus, despite the growing concentration of the commodity flows in the main EU ports which strengthen their competitive position on the open European seaport market, the majority of them seem to be unable to resist the enormous global challenges. However, since the mid 90. some European seaports are getting much more pro-active on the global transport market which is not the case of Polish ones yet. The simplest form is the EU biggest container terminal operators (Eurogate) set together with the strongest railway companies container railway services which operate as a global player on the European transport market. Such services connect the main European terminals (Bremen, Hamburg) with the main consumer and production centers in Europe. Consequently, European ports binds huge area of the hinterland and the main initiative is overtaken by the container terminals.

The wider concept, based on stronger position of container terminal operator in land transport relations is aimed at strengthening its position in relation to the container transport operator (container alliances). Nevertheless, the port container operators are partly overtaken by still stronger maritime transport operators. In fact, the shipping lines become multimodal logistics providers controlling the routing of the flows in conjunction with the ocean services of the consortia. Thus, a port is an incidental entity in this global network system. Containerisation has reduced the economic impact of ports on cities, because ships crews are smaller than they used to be, spend little time in port and dock labour considerably diminished. As local economic benefits (employment) are declining, it is no longer justified to invest huge public money in the port area. The European Commission wants to minimise subsides in accordance with proper competition policy and a restrictions on public state aid.

The increased competitiveness of the Polish ports can be achieved by establishing port clusters either via their port authorities or via municipal governments. The port cluster may be defined as ‘the set of interdependent firms engaged in port related activities, located within the same port region and possibly with similar strategies leading to competitive advantage and characterized by a joint competitive position vis-à-vis the environment external to the cluster’(Hong-Seung-ROH 2004). There is an urgent need to enhance the relationships between the port and associated companies in the port area in order to create an added value (Notteboom T. E. 2005). Moreover, the strategies for port competitiveness must take into account local impact in order to strengthen the link between the port and its city/region (Pando J. et al.2005).

Port management systems should also meet the criteria of sustainability, i.e. combining economical, ecological and social factors. The sustainable composition will be reached if all stakeholders having different goals are taken into account (Musso E. 2006). It is not an easy task, as ports authorities may be often in conflict with legislation, environmentalists and the general public while trying to accommodate their sites to growing economic needs (f. ex. access to water depths requiring a frequent dredging). There is a need for more partnership solutions as regards port management, implementing ecological systems preventing pollution and excessive emissions. This requires paying more attention to local labour markets in order to avoid social protests (EU ‘service’ directive proposal, for example). The possible reaction leading to raising ports’ competitiveness could be also a horizontal integration and port networking and combining competition and cooperation.

So the Polish seaports need to be much more efficient in micro and macroeconomic terms. They should become an integral part of the vertically integrating logistic transport chain. The simplest form of performing these strategy is the development on their areas the distribution and logistics centres, for example. This is the case of three major seaports in Poland: Gdansk, Gdynia and Szczecin-Swinoujscie (fig. 2) where such investments are taking place. They also need to enforce much more integrated, logistic transport chain oriented sea port activities because of the still growing competitive requirements from maritime and land transport operators, as well as exporters and importers. Such kind of seaport reorientation can not be efficiently carried out without a transformation of their administration and management systems, i.e. going towards more partnership solutions, for instance. Some of them will have to find other solutions and cultivate niches as secondary ports. Others may be forced to be pro-active and work closer with logistics providers, railroads and truckers raising the service attractiveness of the port.

However, the abovementioned strategies would require more partnership solutions, going far beyond

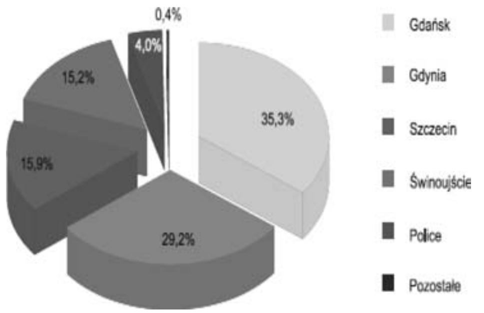

Figure 2. Transshipment turnover in Polish seaports (2007)
Source: Porty morskie, www.start.gov.pl, 19.10.2008.

the port area. Ports could also allocate births to a single user in exchange for along-term commitment which would integrate and even completely attach shipping lines to the particular port. The development of logistics features: inventory control, data management, packing and processing could also enhance economic benefits of port operations, like in Port of Rotterdam. The horizontal port alliances seem to be a good solution for survival, as well. A group of northern European ports already gather together to solve common problems. However, this process is quite a challenge because of the differences concerning port management models and systems. Finally, the Polish seaports' position in relation to global carriers can be upgraded thanks to the privatisation processes (difficult to undertake, because contested by trade unions in Port of Gdynia, f. ex.) and emergence of grouping of terminal owner/operators (Przybylowski A. 2007).

4 CONCLUSION

1. Polish seaports are under a very strong influence of the globalisation and integration processes. Vertically integrating transport chains make them, especially such seaports as Polish ones, vulnerable to rapidly changing contemporary environment.
2. The European Commission acknowledges that the growth in trade and shipping is dependent on having adequate port capacity and recognises that this need is under competition from environmental objectives. It is not clear yet whether the EU wants to support bigger (Rotterdam, f. ex.) or less developed European ports (like Polish ones). In fact, this dilemma is a choice between the highest competitiveness and the sustainable development of the European territory.
3. Traditional port management models and the state of the transport infrastructure decrease the competitive position of Polish seaports. Thus, there is a need for novel organisation solutions and more investment in the infrastructure and superstructure also in order to enhance their competitiveness.
4. The appraisal of the seaports' position in Poland is possible through capital integrated transport chain oriented models of management. Actually, the efficient seaport policy needs to take into account such strategies as vertical and horizontal integration, port networking and port clustering.
5. Some Polish seaports will have to find other solutions and cultivate niches as secondary ports. Others may be forced to be pro-active and work closer with logistics providers, railroads and truckers raising the service attractiveness of the port. However, this would require more partnership solutions, going far beyond the port area. Ports could also allocate births to a single user in exchange for along-term commitment which would integrate and even completely attach shipping lines to the particular port. The development of logistics features: inventory control, data management, packing and processing could also enhance economic benefits of port operations, like in Port of Rotterdam. The horizontal port alliances seem to be a good solution for survival, as well.

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14.5
An analysis of marine navigation and safety of sea transportation by Iranian women as officer and master mariner

H. Yousefi
Chabahar Maritime University, Chabahar, Iran

ABSTRACT: The author attempts to describe the safety factors which should be considered for the sea transportation through coastal waters and the International waterways. First segment of this paper is designated to investigate the role of females as crew and officer on board ships. Based on STCW95 Convention and from the professional point of view the author believes that the Iranian females can be able to take responsibility on board ship as officer or even master mariner. Boys and girls can learn the required theories at the college when they are Cadet and improve their skill on board ship; therefore, operation of the advanced equipment on board ship can be done by both sides easily. A section of this paper is devoted to elucidate the various aspects of Iranian culture for the sea jobs which are going to be carried out by Iranian women on board ships. Some technical suggestions will be described in this paper in order to be taken into account the cultural factors by the IMO representative and finally the Parliament of Islamic Republic of Iran. The existence of women especially Iranian women or the mixture of men and women officers on board Iranian ships in order to improve the safety factors of sea transportation will be discussed in depth.

1 THE HISTORY OF JOINING WOMEN ON BOARD SHIP AS STEWARDESS AND OFFICER

One radio operator met a female radio operator while being briefed on communications procedures during a convoy conference in Port Said, Egypt in 1944. She was the only operator on board the Norwegian flag tanker. As the operator stated that *"We were both headed for the Persian Gulf…we, with a load of Russian bound materiel, and her, to load oil."* Women have bravely served the U.S. Navy for nearly a century, but they have only been allowed in positions aboard non-hospital ships for the last 25 years. In October 1978, in the wake of a court ruling that overturned statutes that forbade women from serving at sea, the Navy launched their Women in Naval Ships program and announced that they would assign 55 women officers and 375 female enlisted personnel to 21 ships during the next year. Women were finally allowed to serve as surface warfare officers and in numerous enlisted ratings (below the rank of officer) on such auxiliary vessels as submarine and destroyer tenders and oceanographic research ships. In 1977, the first woman cadet in Irish shipping Ltd. was Ms. Ann Parry. Irish Shipping Ltd. (1941–84) had a number of women crew members including the first women officer on an Irish ship Marilyn Stockwell from Tuam, Co. Galway. Marilyn sailed on the Irish Maple in 1973 as the junior radio officer. In 1974 the first women deckhand on Irish Shipping Ltd. Miss Rosemary Dalton joined the Irish Oak. During Fiscal Year 1979, 55 officers and 375 enlisted women will be assigned to 21 US. On November 1 1978, naval ships in both the Atlantic and Pacific fleets, with the first officers reporting aboard their respective ships. The first enlisted women will report in December. Mrs. Linda Hayes (Linda Purdy) of the Irish ferries vessel M.V. *Ulysses*. She was in 1987, along with Ms. Rosemary Docherty the first woman purser in the 150 year history of the B+I Line. Also in 1987 the first women officer on a B+I ship Ms. Caroline Meaney, joined the M.V. *Tipperary*. In 1987, women started to work at sea as purser and stewardess which lead the management team on the Irish ferries and passenger ships. Nowadays, there are more women on board ships as Radio, Deck and even Engine officers in shipping companies belong to European, American, Australia and Far East countries. During the eighteenth century, the British Admiralty did not allow women to be on board, but records show that captains often let the wives of officers join the ship and share their husbands' cabins or hammocks and food rations in the British navy. As a result of technological improvement in shipping in the last couple of years; the new ships are designed and equipped with the computerized systems. The author has to draw your attention to the safety factors which should be considered for the sea transportation through coastal waters and the International waterways in this article. Although, US women were interested in joining on board warships even during wartime, nevertheless the US government limited their contribution on board naval ships. When passenger ships were taken over by the government after the U.S. entered World War II, many women who had served as stewardesses, hairdressers, etc. lost their jobs. They were required to leave after their ships returned to port after December 7, 1941. One of these women, Betty Jackson, wrote to President Roosevelt: "*We are not afraid of the dangers and we are willing to put up with any inconvenience as long as we can be reinstated and go back to sea.*" Admiral Land, head of the U.S. Maritime Commission replied that there were no provisions on wartime ships for women crewmembers.

2 A SURVEY FROM THE ILO ABOUT WOMEN AT SEA

In an October 3 press release, the U.N. International Labour Organization (ILO) said a new study of women at sea "paints a grim picture of the struggle faced by women to gain employment and advancement but says women represent a potential resource for the industry." The study highlights a need for policies that address issues related to sexual harassment, menstruation, pregnancy, contraception, maternity, and sexual and general medical health, the release said. While some ship owners, managers and trainers of women are positive about their performance, women often still face intolerance and harassment, the release added. Researchers examined regional variations of women at sea such as the fact that in some Scandinavian countries women make up more than 10 percent of the seafaring workforce, while their numbers in other European countries "are negligible". As the ILO said that Countries belonging to the Organization for Economic Cooperation and Development (OECD) provide the largest proportion of women employed on cruise ships, 51.2 percent; followed by Eastern Europe, 23.6 percent; the Far East, 13.7 percent; Latin America and Africa, 9.8 percent; and South Asia and the Middle East 1.7 percent. The labour agency stated that only 7 percent of women seafarers are officers compared to 42 percent of their male counterparts. However, it said, women students at the World Maritime University (WMU) have risen to 21 percent of the university's population compared to 8 percent in 1995.

On a more positive note, the study reveals significant progress in training policies over recent years. By 2001 the total number of female students at the World Maritime University (WMU) had risen to 21 percent of the total university population in comparison to 8 percent in 1995. The ILO study is based on a survey commissioned by the ILO following the resolution concerning women seafarers adopted by the 29th Session of the ILO/IMO Joint Maritime Commission, 22–26 January 2001, in Geneva. The Resolution called for a more active role to be taken in promoting the integration of women in the industry. As a follow-up to the Resolution, the study identifies good practice and recommends measures that may further help the integration of women into shipboard communities.

Outside Europe figures also vary: women make up 1.1 percent Brazil's seafarers, and 5 percent of Indonesia's. According to Fairplay in 1998, India reported only three women out of 43,000 registered seafarers; by the end of 2002 there were twelve. In the Philippines, the largest supplier of seafarers to the world merchant fleet, only 225 women out of 230,000 seafarers appear on the international seafarers' register for 1983–90. The bulk of women seafarers are concentrated in the hotel personnel of cruise ships, and these are mostly in rating grades. Only 7 percent of women seafarers are officers and the rest (93 percent) are ratings. By comparison, 42 percent of male seafarers are officers and 58 percent are ratings. And there are further anomalies in seafarers' employment. Currently, OECD countries recruit the largest proportion of women employed on cruise ships (51.2 percent), followed by Eastern Europe (23.6 percent), the Far East (13.7 percent), Latin America and Africa (9.8 percent) and South Asia and the Middle East (1.7 percent). On the other hand, most male seafarers are recruited from the Far East (29.1 percent), followed by 23.3 percent from OECD countries, 17.8 percent from Latin America and Africa, 12.3 percent from Eastern Europe, 7.5 percent from South Asia and the Middle East.

3 IRANIAN WOMEN AS OFFICER AND MASTER MARINER ON BOARD SHIP

This segment of the paper is designated to investigate the role of Iranian females as officer and master mariner on board ships. Of course, the Iranian women can work on board coastal water craft as an officer or Captain at the Persian Gulf or even further routes. It is difficult to offer sea jobs to the Iranian women; it is because of the Iranian culture! Nevertheless, from the religious point of view, man and woman have equal right to live; therefore the only problem is the long voyages at sea for the Iranian females. It means that Iranian females can be able to take responsibility on board High Speed Craft or passenger ships as officer or master mariner in short voyages at the Persian Gulf. The other alternative to solve this problem is that the Iranian women can join on board ocean going vessels as officers accompany with their husband in peace of mind. As result of that they can stay on board ship more than usual period and their efficiency for doing the job will be improved greatly. It should be noted that Iranian females can be officer and finally master mariner on board coastal and ocean going vessels, because the situation on merchant ships has been changed and great number of Iranian women are interested in travelling by passenger ships; therefore, it is necessary to have women officers on board Iranian ships in order to look after the female passengers especially in emergency situation. Nowadays, as a result of the technological improvement in shipping and increasing the price of airplane ticket, etc; use of ferries, high speed craft and passenger ships became more common for short voyages at the Persian Gulf. It should be noted that Iranian passengers are interested in using ships for pilgrim journeys in order to go to Saudi Arabia and Syria. Iranian shipping companies allow the wives of officers join the merchant ships and share their husbands' cabins, food, etc; although the life at sea is awful, nevertheless majority of Iranian women are interested in joining the ocean going ships as officer in order to be with their husband. One of the problems of joining the Iranian females on board ships can be related to their uniform which should be Islamic dressing with a cap and scarf or even a useful cap similar to the Iranian Airline uniform.

4 CONTRIBUTION OF WOMEN AS STEWARDESS ON BOARD WARSHIPS

Why would a woman leave home to travel by a ship of war? Of course, many had no home or money while their husbands were at sea. The ship provided a home and a chance to share life, however harsh, with their husbands. The wives worked on the ship, mending or cleaning clothes or serving as captains' maids. In battle, they attended the wounded or carried gunpowder; a few were wounded themselves. Childbirth at sea was not uncommon, and sometimes a ship's guns were fired to speed up a difficult birth—a practice that gave rise to the saying, "a son of a gun."

Women played only a small role in the Canadian merchant navy, there were some pioneers working as stewardesses, and a few Canadian women were radio officers on ships of the Norwegian merchant navy (the only Allied merchant fleet at that time that permitted women to serve aboard ships as wireless operators). Hannah Baird was the first Canadian female who casualty of the Second World War. Just hours after Britain declared war on Germany on September 3, 1939, the passenger liner Baird was working aboard was torpedoed by a German submarine. You won't find Stewardess Hannah Baird's name in the history books, or the names of the other seven Canadian women who died while serving in merchant ships during both World Wars. Maude Elizabeth Steane, a ship's radio operator during World War II, had to leave Canada to find a ship because women were not allowed to join any ship in Canada. Just ten weeks after leaving home, Maude Steane was killed. It is often reported that she died by enemy gunfire while her ship was docked in Naples, Italy.

Clara Gordon Main, a stewardess on the SS President Harrison was among the first American Prisoners of War. The ship was captured by the Japanese on December 7, 1941, while rescuing U.S. Marines from China. The vessel was first bombed and then captured by the Japanese who ordered all hands to abandon ship. In so doing the Chief Steward suffered several broken ribs. Mrs. Main, the only woman member of the large crew, conducted herself in such a cool and collected manner that she had a decidedly steadying influence on the seamen. She also had the foresight to take with her, as she left the ship in the last boat, certain medicinal restoratives and first aid material, which proved invaluable. During six weeks subsequent treatment, she nursed the Chief Steward so effectively that she undoubtedly saved his life.

5 CONTRIBUTION OF IRANIAN WOMEN IN SPORTS AND DIFFERENT ACTIVITIES

In the last couple of decades, the Iranian women contributed in different field of sports that could get medal and good score at the international games. Climbing a mountain is a good, safe and interesting sport for Iranian females, especially for those who are living near mountainous areas. Iranian female football team with Islamic dressing plays well; the team could get the highest grade in Asia ranking teams. Boatwomen is an exciting group sport which is quite interesting by Iranian females; it is because of their convenient for dressing and team work activities.

Iranian women working as police officers at the main cities of Iran, those who like such activity should be brave and energetic in order to show their capabilities which are more or less similar to the police men. In fact, contribution of Iranian females as fire fighter teams proves that they are brave to perform such hard and dangerous activities. It should be noted that the job of fire fighter in comparison to the seafarers' career is more hazardous, because they should be as quick as possible.

The magnificent activity of Iranian female has been done by Mrs. Anoush Ansari. She was the first private space explorer women who travelled around the earth up to the International Space Station. She also earned a place in history as the fourth private explorer September 18, 2006; Anousheh Ansari captured headlines to visit space as the first Iranian astronaut. On 5th January 2008, Guardian Newspaper announced the list of 50 persons who could save the earth from the environmental hazardous; as result of that name of Mrs. Dr. Masomeh Ebtekar, Iranian environmental minister, as Survivor of the earth environment was in the list.

6 SAFETY OF NAVIGATION BY JOINING IRANINAN WOMEN ON BOARD SHIPS

Iranian women seafarers can join on board the ships according to their speciality; it seems that the shipping company can employ them as officer for catering, radio and deck department of a ship. Ship voyage at the Persian Gulf is short; therefore the female officers may take only one sea watch during the voyage. By referring to the previous experiences of so many shipping companies in all over the world, 3 out of 54 percentages of women were deck officers. It means that as first experience, it is better that the Iranian female join on board the ship as stewardesses, cooks, assistant doctor, chief stewards, radio officer, etc. after that as deck officer in order to become a ship Captain. So, this process should be started in short voyages at the Persian Gulf.

The following pie chart has been acquired through a survey from Iranian women who work at marine organizations in Chabahar port and some of the students from Chabahar Maritime University. Although those who contributed to answer the questioner of this survey, knew that work at sea is hard, nevertheless half of

Figure 1. Sea life survey from Iranian women.

them selected "Good" point and the minority of them selected "Bad" point. This survey shows that majority of the Iranian student girls from the University like to be at sea and are keen to join on board the ship as officer.

A student girl in oceanography should travel by research ship at the Persian Gulf for about a couple of days in order to do the specific research about aquatic, sea animals, wave height, etc. Therefore, referring to the Iranian culture it is more safe and convenient for the girl to travel and to collect data by the female crew on board the ship. Ship manoeuvring and the safety of navigation at the Persian Gulf are not depend on the sex (female or male) of the seafarers; it is related to a qualify officer who should comply with the IMO regulations. Since the required training based on STCW95 Convention and the written and oral examination of the Certificate of Competency have been passed out by the candidate (boy or girl); after that he/she will be qualify to run a ship. All watch keepers shall be qualified and hold certification prescribed for navigational watch to the standards prescribed in A-II/4 of STCW 95 according to the duties they are required to perform. As consequence of the above explanation, the main issue is the knowledge and skill of the seafarer to support the safety of life at sea; so, bridge safety equipment can be operated either by man or woman officer and both are safe and sound.

7 CONCLUSION

Iranian peoples are interested in travelling by ship for leisure and pilgrim journeys, because they are quite cheap, comfortable and safe for short journey at the Persian Gulf and even long voyage up to Saudi Arabia and Syria. By increasing number of passenger ships in Iran and the establishment of passenger terminals in South and North ports of Iran, therefore the existence of Iranian women crew on board ship in order to look after the female passengers is necessary and essential. Referring to the STCW95, the important factors for improving the safety of sea transportation are skill and qualification of the seafarers and are not related to the sex of the ship officers.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

14.6 Modelling support for maritime terminals planning and operation

S. Ricci & C. Marinacci
"Sapienza" University of Rome, Rome, Italy

ABSTRACT: The maritime terminal design process is a complex stepwise series of strategic decisions involving the engagement of a relevant amount of resources. In fact operating conditions near the maximum capacity cause congestion effects with negative consequences on regularity and quality service. Therefore, in order to maximise its effectiveness, a strong need of methodological support is required. With this aim the authors developed different methods and models capable of supporting some of these decisions: a regressive method for preliminary dimensioning of harbour terminals and a sea-side operation combinatorial model for traffic analysis and capacity estimation. They are able to be integrated in a chain of models taking into account dimensions and manoeuvrability of ships, terminal morphology, handling equipment, storage areas, etc., with the aim to support the planning process and operational management.

1 INTRODUCTION

The design process is a complex stepwise series of strategic decision involving the engagement of a relevant amount of resources.

Therefore, in order to maximise its effectiveness, a strong need of methodological support is required.

With this aim the research group of the authors developed different methods and models capable to support some of these decisions:

- regressive method for preliminary dimensioning of container terminals;
- sea-side operation combinatorial model;
- synthetic method capable of validating the estimates of the capacity combinatorial model.

It is possible to integrate the models in a chain taking into account, within a stepwise methodological approach, dimensions and manoeuvrability of the ships, positions of terminals, accessibility, handling equipment, storage areas, etc.

2 PRELIMINARY DIMENSIONING METHOD

The preliminary dimensioning method allows to select the parameters most suitable to describe terminals, to determine their dimensional and equipment characteristics and to verify their production, as well as to provide inputs, defined in terms of production or number of ships, for the combinatorial model capable of evaluating sea-side port capacity (Florio & Malavasi, 1995).

2.1 *Definition of key parameters*

Maritime container terminals are infrastructures provided with equipment for the transfer of containers from ship to docks and back.

They are integrated into logistic structures of most commercial ports.

In any terminal fundamental and complementary activities are identifiable:

1 container loading and unloading;
2 sea-side and land-side (railway and road) stocking operations;
3 traffic management and control;
4 container clearance for international traffic;
5 storage and reorganisation of freight into containers.

Structures and performances of terminals, deduced from a first analysis, may be synthetically represented in three main clusters of parameters (Noli & al. 1984) respectively representing dimensions, equipment and production:

A. Dimensional parameters:
   1) Quay length,
   2) Total stacking area,
   3) Covered stacking area,
   4) Uncovered stacking area;
B. Equipment parameters:
   5) Number of gantry cranes,
   6) Number of other cranes,
   7) Number of storage cranes,
   8) Number of various loaders;
C. Production parameters:
   9) Number of handled containers.
   10) Number of handled TEU,
   11) Number of handled container tonnage.

For these parameters an extensive investigation on port terminals for data acquisition has been carried out.

2.2 *Definition of the area of analysis*

The ports analysed are located in Northern Europe (Atlantic Ocean, Baltic Sea and North Sea) and in Mediterranean area (Ricci & al. 2008b).

Table 1. Observations available for analysed parameters.

Parameters	Observation N°
Quay length	93
Total stocking area	91
Covered stocking area	91
Uncovered stocking area	29
Gantry cranes	85
Other cranes	37
Storage cranes	59
Various loaders	57
Containers	19
TEU	72
Tonnage	30

N	1	2	3	4	5	6	7	8	9	10	11
1	-										
2	88	-									
3	77	91	-								
4	23	29	28	-							
5	72	79	79	20	-						
6	29	35	28	10	24	-					
7	49	74	46	10	48	22	-				
8	47	51	39	10	45	23	40	-			
9	14	19	19	5	18	8	12	12	-		
10	55	69	63	17	61	25	46	32	17	-	
11	20	28	27	8	27	16	18	20	12	29	-

Figure 1. Available observations by couples of parameters.

In this area 73 ports, dealing with relevant container traffic, have been identified.

For 93 container terminals located in 49 of these ports useful data have been collected and elaborated.

In Table 1 the amount of observations available for the analysed parameter is shown.

2.3 *Application of methodology*

In the proposed regressive approach an analysis has been performed on the relationships between parameters:

1. belonging of the same cluster (as defined above);
2. belonging of different cluster.

The amounts of data useful for the correlations are summarised in a matrix (Fig. 1).

The collected and homogenised data has been correlated by means of a linear regression obtaining the correlation coefficients *R*.

All the values have been filtered with different *R* threshold values (0.7 and 0.8).

In Figures 2 and 3 the values of coefficient R of the regression lines are presented in matrices.

On this basis it is possible to represent the relationships between parameters corresponding to shortest paths on graphs of Figure 4.

2.4 *Direct and indirect correlations between parameters*

The main feature of the proposed methodology is the possibility to calculate on a probabilistic basis the main design parameters (dimensions, equipment, etc.) by means of the correlations with flow parameters and to calculate flow and equipment parameters by means of the correlations with dimensional parameters.

For this purpose it is necessary to determine also the direct relationships and the indirect ones requiring intermediate parameters to link inputs and outputs.

For the selection of shortest paths (highest global correlation) the Dijkstra algorithm has been applied.

Starting from the inputs corresponding to production parameters (containers, TEU and tonnage) or to dimensional ones it is possible to define the tree of shortest paths with the parameters linked directly and indirectly.

Different scenarios have been obtained by combination of threshold value (0.7 and 0.8) of correlation parameters with possible input parameters (Figures 5–11).

2.5 *Case study*

The regressive method (Ricci & al. 2008b) has been applied to the pilot case represented by the Darsena Toscana container terminal in the port of Livorno (Table 2).

On the basis of arrivals and departures of container ship to/from Calata Massa, relating to Terminal Darsena Toscana quay, it has been possible to determine the capacity margin in 2007 expressed in number of ships per day that are can be moored alongside the above-mentioned quay.

The comparison between values of dimension, equipment and production parameters estimated by the model and real values are summarised in Figures 12–15.

2.6 *Remarks*

The values of parameters estimated by means of *R* threshold (0,7 or 0,8) are comparable, therefore their choice may be considered not relevant.

The most reliable results are obtained by means of production parameters as input data, in particular the number of handled container for the determination of quay length, total stocking area and gantry cranes. Indeed the other parameters are strongly influenced by local organizational issues and for this reason less suitable to be dealt with in a general approach.

1	QUAY LENGTH	1										
2	TOTAL STOCKING AREA	0,892	2									
3	COVERED STOCKING AREA	0,518	0,963	3								
4	UNCOVERED STOCKING AREA	0,621	0,971	0,921	4							
5	GANTRY CRANES	0,745	0,925	0,228	0,032	5						
6	OTHER CRANES	0,217	0,410	0,118	0,827	0,000	6					
7	STORAGE CRANES	0,769	0,805	0,905	0,100	0,809	0,232	7				
8	VARIOUS LOADERS	0,551	0,601	0,551	0,330	0,542	0,212	0,764	8			
9	CONTAINER [NUMBER]	0,349	0,925	0,966	0,825	0,935	0,815	0,844	0,777	9		
10	CONTAINER [TEU]	0,706	0,910	0,207	0,134	0,770	0,224	0,823	0,559	0,999	10	
11	CONTAINER [TONNELAGE]	0,513	0,945	0,983	0,173	0,947	0,462	0,936	0,738	0,999	0,996	11

Figure 2. Correlations between couples of parameter with 0.7 as threshold of relevance.

1	QUAY LENGTH	1										
2	TOTAL STOCKING AREA	0,892	2									
3	COVERED STOCKING AREA	0,518	0,963	3								
4	UNCOVERED STOCKING AREA	0,621	0,971	0,921	4							
5	GANTRY CRANES	0,745	0,925	0,228	0,032	5						
6	OTHER CRANES	0,217	0,410	0,118	0,827	0,000	6					
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11	CONTAINER [TONNELAGE]	0,513	0,945	0,983	0,173	0,947	0,462	0,936	0,738	0,999	0,996	11

Figure 3. Correlations between couples of parameter with 0.8 as threshold of relevance.

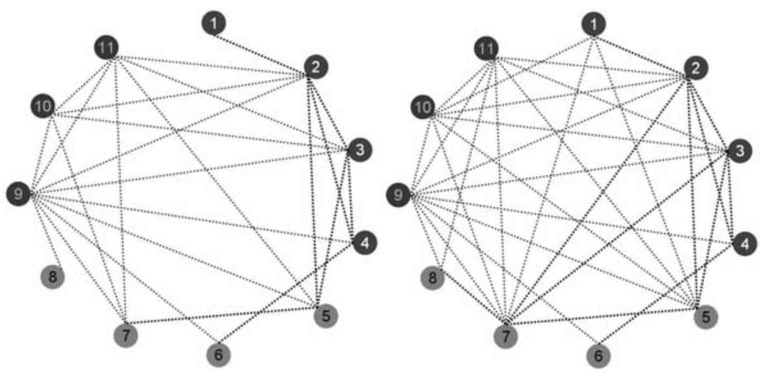

Figure 4. Graphs of the relevant correlations with R > 0.7 and R > 0.8.

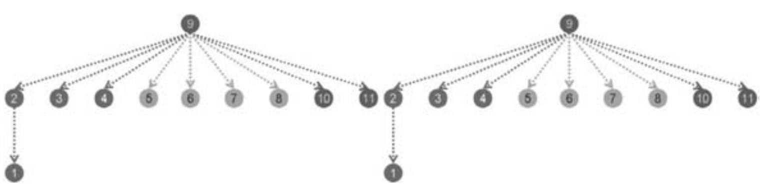

Figure 5. Shortest paths starting from the number of containers (threshold R > 0,7 and R > 0,8).

Figure 6. Shortest paths starting from TEU (threshold R > 0,7 and R > 0,8).

Figure 7. Shortest paths starting from containers tonnage (threshold R > 0,7 and R > 0,8).

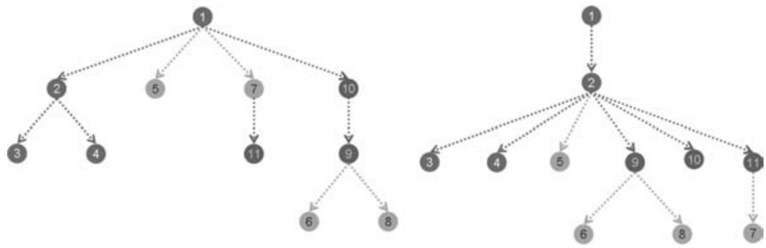

Figure 8. Shortest paths starting from quay length (threshold R > 0,7 and R > 0,8).

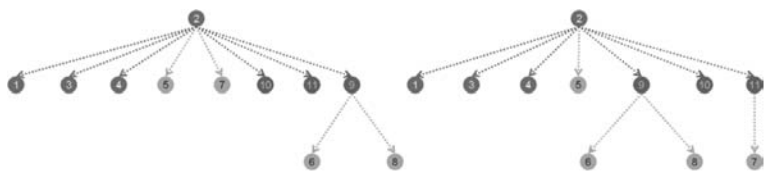

Figure 9. Shortest paths starting from total stocking area (threshold R > 0,7 and R > 0,8).

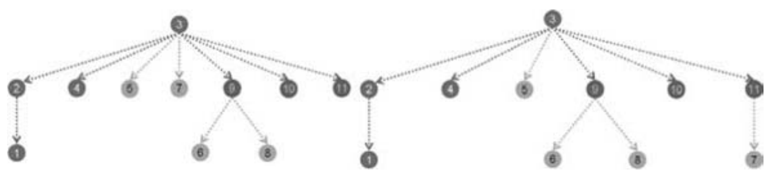

Figure 10. Shortest paths starting from covered stocking area (threshold R > 0,7 and R > 0,8).

Figure 11. Shortest paths starting from uncovered stocking area (threshold R > 0,7 and R > 0,8).

Table 2. Leghorn Darsena Toscana container terminal (2007).

Parameters		Data
Quay length	[m]	1.430
Total stocking area	[m^2]	412.000
Containers	[n]	323.708
TEU	[n]	500.000
Tonnage	[t]	6.677.350

3 SEA SIDE OPERATION COMBINATORIAL MODEL

Sea-side port operation, characterised by the overlap of the traffic of many different ships traffic often causes congestion effects with negative consequences on transport service regularity.

In this framework models (Potthoff, 1979) capable of simulating the operation of sea-side port terminals, of evaluating their capacity and of calculating the

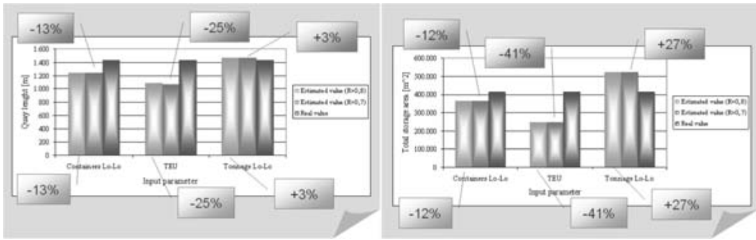

Figure 12. Comparison between estimated and real values of quay length and total storage area.

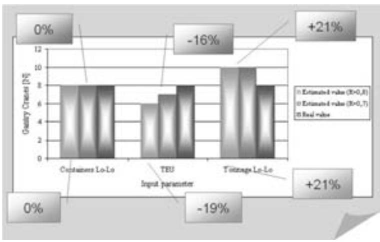

Figure 13. Comparison between estimated and real values of gantry cranes.

occupation time of the terminal by ships and its utilisation degree both in regular and perturbed (because of external causes or the congestion itself) conditions and of relating it with the quality of the transport services are very effective and allow to reach specific objectives:

– operational time saving;
– rational land-use (better planning of sea front);
– prevention of losses due to possible accidents and incidents;
– sensitivity of performances to variations in port terminal lay-out.

3.1 *Specific research objectives*

From the above arise considerations the specific objectives of the present researches that is build up models capable of:

1) simulating the terminal operation;
2) evaluating the terminal carrying capacity;
3) relating the utilisation degree of the terminal with its service quality.

The application of combinatorial synthetic models to sea terminals (Ricci & al. 2007) requires the introduction of the factors characterising the ships (dimensions and maneuvering with related kinematic and geometric constraints regulated movements), the terminal itself (different type of basin morphology or layout as shown on Figure 16).

In order to determine time interdiction between ship movements entering/exiting maneuvering movements are divided in 5 phases:

1 Approach to mouth,
2 Access to the channel,
3 Rotational movement,
4 Approach to the quay,
5 Anchorage.

The carrying capacity of the terminal corresponds to the maximum number of movements allowed during the reference time and it depends mainly upon the following factors:

– time distribution of entering and exiting movements to/from the port and related assignment to the docks;
– terminal topology defined by the location of docks and the mouths.

The model approach is based on a constant probability for the arrivals i.e. a fixed number of movements for each route in the reference time.

This condition well represents both:

– high frequency of arrivals in peak periods;
– usual data availability in the planning phase, without detailed information on ship scheduling.

This condition is formally defined by an array P, with dimensions corresponding to the number of the routes in the terminal and single elements p_i defining the number of movements on each route in the reference time T.

The analysis of the terminal morphology allows to define the whole set of routes and their reciprocal compatibility/incompatibility represented in a square matrix (compatibility matrix) $C = P \times P$, with each element c_{ij} representing the condition of compatibility/incompatibility between routes i and j.

The possible relationships are:

– incompatibility between two routes with:
  a. common final/initial sections,
  b. common middle sections,
  c. same path but opposite direction;
– compatibility between two routes without common sections, allowed to be run contemporarily.

The proposed approach allows to calculate the mean number of possible simultaneous movements n by taking into account the compatibility of the routes and their frequency of utilisation:

$$n = \frac{N^2}{\sum_{ij} m_{ij}} \tag{1}$$

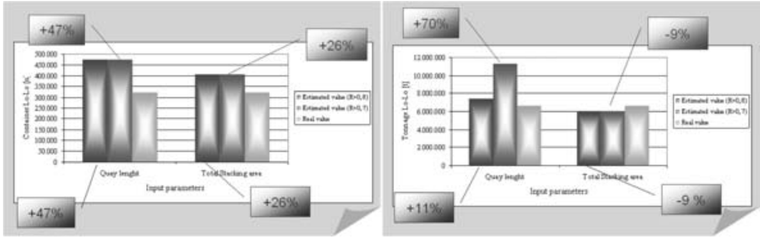

Figure 14. Comparison between estimated and real values of container Lo-Lo and tonnage Lo-Lo.

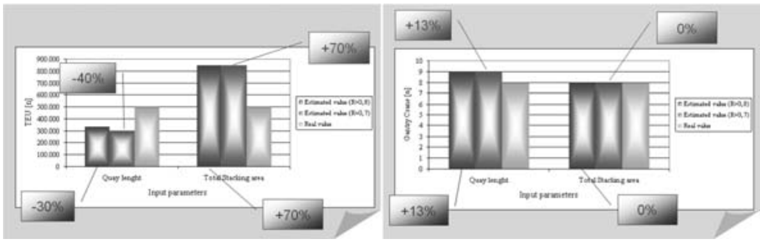

Figure 15. Comparison between estimated and real values of TEU and gantry cranes.

Figure 16. Typical port layouts subjected to analysis.

where:
– $m_{ij} = p_i \times p_j$ if i and j are incompatible;
– $m_{ij} = 0$ if i and j are compatible.
– N is the total number of movements during reference time T.

In a similar way the mean terminal utilisation time can be defined as:

$$t = \frac{\sum_{ij} m_{ij} \cdot t_{ij}}{\sum_{ij} m_{ij}} \tag{2}$$

where t_{ij} is the time during which the route j may not be run because a ship is moving on the route i (interdiction time).

The total occupation time can be calculated as:

$$B = \frac{N}{n} \times t \tag{3}$$

In order to take into account the waiting situations due to simultaneous arrivals on incompatible routes it is possible to calculate the delay imposed by the p_i movements on the p_j movements because of the interdiction time t_{ij}:

$$r_{ij} = \frac{p_i p_j t_{ij}^2}{2T} \tag{4}$$

These parameters allow the comparison between the total utilisation time of the terminal, including the delays, and the reference time.

The utilisation degree can be calculated with reference only to the situation of regular running on routes, as:

$$U = \frac{B}{T} \tag{5}$$

Or reference to the total time, including the delays, as:

$$V = \frac{B + R}{T} \tag{6}$$

where:

$$R = \frac{\sum_{ij} r_{ij}}{n} \tag{7}$$

3.2 *Applications and remarks*

The model has been applied to five Italian ports (Ancona, Bari, Brindisi, Gioia Tauro and Livorno) characterised by three different morphologies (circular, channel and tree layout).

The results of the model application are summarised in Table 3.

The port with a circular morphology normally shows a higher capacity limit than the other ones, due to shorter routes and shorter interdiction times between movements.

The channel ports show a lower capacity than ports with tree layout, due to a lower number of basins that are able to let an early release of common sections between entering/exiting route.

Table 3. Capacity limit for analysed port [movements/day].

Port	Ancona	Bari	Brindisi	Gioia T.	Livorno
Observed movement	33	23	27	18	41
Maximum capacity	61	70	49	40	53

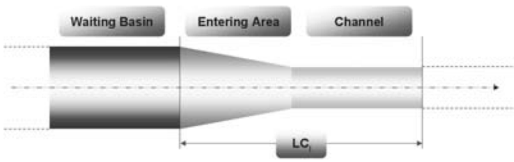

Figure 17. Port schematisation for channel capacity method.

For these ports largest capacity are related to number of quay basins and consequently to their rotation basins as well as to the assignment of docks to ships characterised by less manoeuvrability (e.g. liquid/solid bulk and container ships) in specific part of ports.

4 COMPARATIVE MODELS

In order to validate on a comparative basis the previous model and its results, two alternative models for the evaluation of port capacity have been identified; they are based on:

- Channel capacity,
- Minimum spacing.

These models are characterised by a fewer input data and able to analyse the particular basin channel morphology or a specified part of a port terminal referable to this specific characteristic (Ricci & al. 2008a).

4.1 *Models based on channel capacity*

The port system is schematically structured into three parts (Fig. 17):

- the waiting basin, where ships arrive and wait to enter the channel;
- the entering area, where only the ship approaching the channel is admitted;
- the channel itself.

As soon as the ship in the entering area approach the channel, the following one enters this area at the minimum separation distance.

The following hypotheses are considered for the calculations:

- ship arrivals according to the Poisson distribution;
- infinite capacity of the waiting basin;
- fixed speed for each ship in the channel;
- deterministic separation distance between ships;

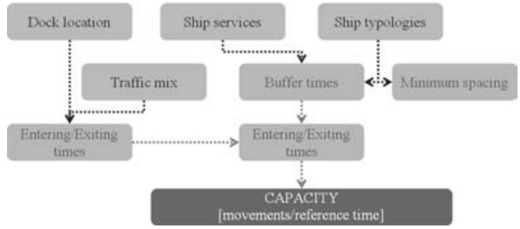

Figure 18. Channel capacity methodology.

- fixed fleet composition;
- permanent communication between ship and traffic controller;
- ship characteristics known in advance by traffic controller;
- irrelevant wind effects;
- permanent availability of pilots and tugboats;
- 24 hours/day operation;
- balanced entering and exiting flows.

By adopting the Permanent International Association of Navigation Congress (PIANC) expression for the stopping distance is:

$$D = 4L \times \left(\frac{V}{2.5}\right)^{0.75} + L \tag{8}$$

This distance is increased to take into account adverse weather conditions (+50%), approximation in speed measurement (+40%) and additional safety rate (+20%):

$$D = \frac{L}{60} \times \left(0.235 \times V^{0.75} + 1.8\right) \tag{9}$$

The minimum separation time S_{IJ} between a couple of ships I and J further depends upon the speed strategy adopted in the channel (single speed or multi-speed) and is calculated at the generic ship I dock, whose distance from the channel entering is LC_I:

$$S_{IJ} = \frac{(D_J + L_I)}{V_I} + (LC_I - D_J) \times MAX\left[\left(\frac{1}{V_I} - \frac{1}{V_J}\right);0\right] \tag{10}$$

The probability P_{IJ} that the generic arriving ship has a separation time S_{IJ} from the following one is the product $P_I \times P_J$ of the corresponding probability of arrival of ships I and J.

Therefore the mean service time is:

$$E(S) = \sum_I \sum_J S_{IJ} P_{IJ} = \sum_I \sum_J S_{IJ} P_I P_J \tag{11}$$

and the maximum arrival rate, corresponding to the capacity of the system, according to this method, may be calculated as:

$$\lambda_{MAX} = \mu = \frac{1}{E(S)} \tag{12}$$

The whole methodology is represented in Figure 18 flowchart.

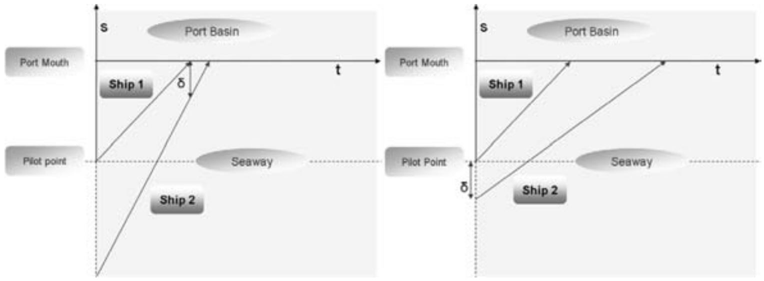

Figure 19. Minimum spacing location.

4.2 *Models based on minimum spacing*

The capacity corresponds to the maximum amount of movements possible within defined time interval under continuous demand service, corresponding to saturation conditions.

The input required by this model is limited to arrival delays, which can be easily calculated or estimated for any port.

Moreover the definition of operational rules, followed by the ships under saturation conditions, is required taking into account that port basin and approaching zones are considered as a whole.

Arrivals always have priority on departures, moreover an exiting ship may be authorised to move only the minimum spacing from the previous movements is reached.

Two possibilities exist (Fig. 19):

– if the second ship is faster than the first one the minimum spacing *d* will be located at the port mouth;
– if the first ship is faster than the second one the minimum spacing *d* will be located at the pilot point (where the ship is manoeuvred by personal of The Port Authority).

The perfect coordination of arrivals is obviously impossible, therefore the spacing is normally higher:

$$D = d + B \tag{13}$$

where *B* is a buffer depending upon the traffic regularity level, which is normally possible to define according to a standard normal distribution.

Moreover a departure may be allowed only if the crossing with the first arriving ship is located at a spacing *D*.

Therefore, if a departure (ship 1) is followed by an arrival (ship 2) the time interval between two departures (ships 1 and 3) is defined as:

$$\Delta t_{13} = t_{u1} + \frac{D}{V_1} + \frac{D}{V_2} t_u + t_{e2} \tag{14}$$

where:

– V_1 and V_2 are the speeds of the ships outside the port mouth;
– t_{u1} and t_{e2} are the mean exiting and entering times for the ships, calculated according to traffic mix and dock location;

The whole methodology is represented in flowchart Figure 20.

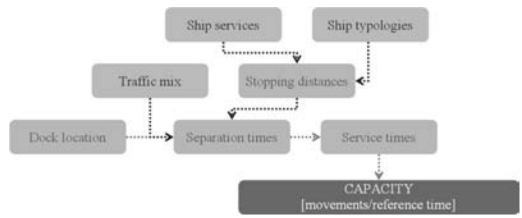

Figure 20. Minimum spacing methodology.

Table 4. Comparison of model results [movements/day].

Model	Gioia Tauro	Livorno
Channel capacity	35	64
Minimum spacing	29	29
Mean number of movements	40	53

4.3 *Applications of the two models and remarks*

The capacity values have been estimated:

– for the port of Gioia Tauro on the basis of the overall number of entering/exiting daily movements (19);
– For the port of Livorno on the basis of the entering/exiting number daily movements in the section before Darsena n˚ 1, Canale Industriale and Calata Gondar basins that is possible to assimilate to a channel.

The key results of the comparison between the model based on the mean number of movements and the alternative models are reported in Table 4.

For the channel port of Gioia Tauro the results are similar.

In the case study of the port of Livorno (tree lay-out) relevant differences exist, particularly for the minimum spacing model, which seem unsuitable for the application to tree lay-out ports.

The original model based on the calculation of mean number of movements seems well reproducing the average capacity volumes for the analysed typical port lay-outs.

5 CONCLUSIONS

A stepwise approach is presented allowing:

- to dimension a harbour terminal (container terminal) in terms of optimal storage capacity, geometrical and operational characteristics, starting from freight handled in a reference time interval;
- to estimate terminal capacity expressed by the number of ships able to use the port equipments in addition to regular and daily traffic inside the port in defined service regularity conditions (under the influence of considered additional movements);
- to identify a qualitative correspondence between analysed different port lay-outs and respective manoeuvring capacity.

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14.7 Turkish maritime transport policy (1960–2008)

M. Kadioglu
Istanbul Technical University Maritime Faculty, Tuzla, Istanbul, Turkey

ABSTRACT: An inward-oriented strategy was adopted for the Turkish maritime sector from 1923 – the foundation date of the Republic of Turkey – to 1952. A partially liberal policy was experienced beginning from 1952, and a planned development period has started since 1962.

This study is aimed at investigating the principles and targets for the maritime sector beginning from the first five-year development plan to the current plan including 2013, and evaluating whether the stated targets have been achieved or not. Moreover it is also planned to investigate the maritime transportation and to state the new opportunities and current issues about Turkey briefly.

1 INTRODUCTION

Activities concerning the Turkish shipping industry and shipyard management in Black Sea, Mediterranean and Marmara Sea coasts were first seen during the Seljuk Empire. Earliest Turkish shipyards – founded at Sinop in the Black Sea in 1214 and at Alanya in the Mediterranean in 1227 – built the 80 or 100–ton boats which were important at that time. Then the Izmir Shipyard belonged to the Aydin Principality was founded in 1326 **(Kadioglu, 1997)**. At the beginning of the Ottoman Empire Izmit, Karamursel, Gemlik, Aydincik and Gelibolu shipyards, and then Istanbul, Suveys, Sinop and shipyards were founded. The ships built in these shipyards were very important for the commerce in the Mediterranean.

The public bodies concerning the Turkish maritime transportation were first founded when the steamboats arrived in Turkey. For the reason that the transportation previously were carried out by the rowboats and sailboats, the history of the maritime transportation starts earlier.

The maritime policies of the Modern Turkey are as following: the period between 1923 and 1952, the Maritime Bank period between 1952 and 1984, and the period beginning from the Turkish Maritime Organizations and the other maritime attempts become independent, and up to now.

The maritime policy of the Turks during the Ottoman Empire period has completely been changed since the foundation of the Republic in 1923. Although Atatürk – the founder of the Republic – wanted the maritime issue to be adopted as a "national ideal", it is seen that Turkey didn't make almost any investments on the maritime issue. The passenger and load transportation were carried out by the classically-built passenger ships between 1923 and 1952 in Turkey damaged in the First World War too much.

From 1923 – the year of the Turkish Republic was founded – to 1950 mostly the railway and maritime line-oriented policies were adopted. As a result of these policies the railway transportation ratio was 55% and the maritime transportation ratio was 27,8% in 1950. The road transportation ratio was only 17,1% in 1950. The maritime line share at passenger transportation was about 7,5% between 1923 and 1952 in Turkey **(SPO, 1962)**.

When the multi-party system has been started in Turkey since 1952, the liberal policies were partially adopted. A planned development plan has been adopted and five-year development plans have been arranged since 1962 in Turkey.

When Turkey arranged and carried out the development plans, there have seen many improvements in the maritime sector as the same in the other sectors.

When the maritime bodies became independent according to the law entered in force in 1984, the Turkish Maritime Organizations (TDİ) to solve the administrative issues concerning the maritime sector and to control it under unique structure, the Turkish Shipping Industry (TGS) to undertake the ship building, Denizbank especially to solve the financial problems of the maritime sector, and finally the Maritime Transportation Company firstly to make the transportations of the public sector were founded. Soon the employment increased in these bodies, the expectations about the autonomy and effectiveness couldn't be met. And then all these bodies were privatized.

2 FIRST FIVE-YEARS DEVELOPMENT PLAN (1963–1967)

For the reason that Turkish economical structure was not strong enough, main principles and general targets of the First Five-Year Development Plan were to benefit best from the current capacity without investing more, and thus to supply passenger and load transportation, and to make services better by decreasing the cost.

Moreover the management targets such as "to collect the harbors under one umbrella" and to build free zones or harbors which will mostly work for transit trade were determined **(SPO, 1962)**.

The Turkish-flag ships to carry at least half of the export goods of Turkey was included in the short-term targets, and "to create a newer and modern merchant marine which will compete with the foreign-flag ship in the international waters" was included in the long-term targets.

3 SECOND FIVE-YEARS DEVELOPMENT PLAN (1968–1972)

In the Second Five-Year Development Plan period (1968–1972) it was aimed at "coordinating all the transportation areas on one hand" and "displaying the general policy of the transportation" **(SPO, 1967)**.

It was the first time it was included to decide for renewing the maritime sector and "competing under the same conditions" with the competitors, and also the "support" in the plan. However it is a conflict that it was both included the "support" and adopting "the ones using system in the transportation sector should make contribution for building and maintenance cost to meet the amortization, maintenance and sustainment cost.

In the second plan it was stated that for the maritime sector to have a progressive, dynamic and keeping abreast of the conditions, "the complete modernization" including management, administration, organization, planning and search subjects in addition to the technical features in the maritime sector was necessary.

4 THIRD FIVE-YEARS DEVELOPMENT PLAN (1973–1977)

For the reason that during the earlier two development plan periods the main targets concerning the administrative regulations about the maritime sector couldn't be carried out, mostly it was again focused on making planning and project studies, and collecting the services under one umbrella at the Third Five-Year Development Plan period (1973–1977).

And so, the targets about balancing the distribution of the transportation between the subsystems, detecting the correlations in issues such as site selection, industrialization and ground use, preparing a project study in order to expand the capacity of at least one harbor in each region in the Mediterranean, the Black Sea and the West regions of Turkey for the industrial transportations were determined.

During the plan period especially in parallel with the increase in fuel prices, it was pointed out that the taxation at transportation, tariff, cost and subvention issues had to be handled and solved in accordance with the new conditions of Turkey.

The Third Five-Year Development Plan period (1973–1977) was the period at which the first concrete target concerning the Turkish maritime sector was seen. In conformity with this target, it was aimed at operating the totally 5.000-capacity 4 ships and 2 trailers in 1975 **(SPO, 1972)**.

5 FOURTH FIVE-YEARS DEVELOPMENT PLAN (1979–1983)

As a result of the petrol prices increased rapidly in the world, carrying out the transportation services with less fuel consumption and the most suitable transportation systems for Turkey, and thus minimizing the foreign-source dependency at the sector were the most important target in the Fourth Five-Year Development Plan (1979–1983). In order to achieve this target, the required measures would be carried out to focus on the mass transportation by directing load transports of the industry to railway and maritime transportation, and the maritime transportation share with the 9,5% ratio in 1977 would be increased to 10,7% in 1983 **(SPO, 1978)**.

Strengthening the infrastructure of the maritime transportation and pipeline transportation, and also the integration was first expressed in the fourth plan period.

In the plan it is emphasized that while preparing the transportation policies, the real cost of the transport in the transportation systems should be detected in order to arrange the tariffs by taking into account the real cost as well as the correlations and effects of the transportation infrastructure systems.

During the Fourth Five-Year Development Plan period (1979–1983) Turkey has understood that the maritime sector would be effective on paying the external debts of Turkey. During the plan period it was claimed that the facilities arisen from the Turkish geographical position should be evaluated and the maritime policies should be determined. Thus it was aimed the importance of being the international causeway to be evaluated for increasing the development and making contribution in order to pay the external debts **(Guner & Kadioglu & Coban, 1997)**.

During the Fourth Five-Year Development Plan (1979–1983) it was aimed the incentive laws, which would encourage the high-capacity load and passenger transport systems, to be entered into force, the big and integrated project concept to be developed, the training, control and engineering services required for the transportation security to be improved firstly, and the zone complexes including the transit circulation and ship maintenance shipyards if necessary to be built while carrying out the new harbor capacities.

The concrete targets about the Turkish merchant marine have been determined also in the fourth plan period. Since the targets of plan were initially to decrease the freight and external debts of Turkey, it was aimed that the Turkish merchant marine to be increased as 800.000 DWT more in the five-year period during the Fourth Five-Year Development Plan (1979–1983) and to be reached 2.600.000 DWT in 1983.

Also in the fourth plan period it was emphasized that the importance of pipeline transportation should be evaluated carefully.

6 FIFTH FIVE-YEARS DEVELOPMENT PLAN (1985–1989)

The targets on the maritime sector to be strengthened, the effectiveness to be increased, the current capacity to be used in the most effective way, the service capacity to be improved, and to make safer were included in the Fifth Five-Year Development Plan (1985–1989).

The road transportation was mostly preferred for the long distance load transport between 1952 and 1985 in Turkey. Since the fuel prices increased and environmental conscious improved, the studies for directing the domestic transports to the maritime transportation – of the unit price was cheaper – was also included in the fifth plan.

According to the concerned target the road transportation share in the domestic transportations would be decreased from 80,9% to 65,7% at the end of the Fifth Five-Year Development Plan period (1985–1989), on the contrary the maritime transportation share would reach 11,5% at the end of 1989 and pipeline transportation share would reach 4,4% **(SPO, 1984)**.

The projects making the traffic safer would be prioritized and the companies working for the maritime transportation would have the lion's share from the international transportation.

Moreover the current harbor invests would be completed during the period, it would be made investment for a new harbor in the Marmara Region of Turkey and the projects would be prepared for building the container terminals at some of the most important Turkish harbors at the international transportation. Firstly important harbors at the international transportation would be improved technically and administratively, and modernized. Thus it was aimed at increasing the harbor capacities and advancing the service level.

It was aimed at making the Turkish Merchant Marine suitable for the international maritime transportation and modern management concept, and the tonnage of Turkish Merchant Marine to be reached 6,2 million tons at the end of Fifth plan. In conformity with those targets it was pointed out "improving" the passenger ships which would make transportation for touristic purpose and local passenger transport.

7 SIXTH FIVE-YEARS DEVELOPMENT PLAN (1989–1994)

During the Sixth Five-Year Development Plan (1989–1994) the maritime sector has also been considered as a transportation system supporting the development of the country without causing any bottleneck because of the growing external debt of Turkey, making the international commerce easier and making contribution for the payment balance of Turkey most.

During the Fifth Five-Year Development Plan period (1985–1989) 22% of the total public investments were shared for the transportation system, and thus it was aimed at spending almost the total of the investments for the current projects and so making contribution for the economy rapidly **(SPO, 1988)**.

During the Sixth plan period it was first expressed "integration with the EU" and aimed at conforming to the European Union on the transportation policies.

It was adopted to prioritize the staff training at "infrastructure" and "management" issues in order to follow the international developments closely and to make services concerning the maritime sector in Turkey as required.

It was also pointed out at this plan period that in order to benefit from the Turkish harbors more at transit transportations carried out over Turkey, it was necessary to make arrangements encouraging this transit at harbor superstructures and tariff systems.

At the end of sixth plan period it was aimed the Turkish Merchant Marine to be reached 6,5 million DWT via construction and import of the ships appropriate for the international technological developments.

During the plan period it was predicted the Turkish Merchant Marine share to be increased 8,1% at domestic load transportation and 4,8% at international load transportation. Besides, it was expected the inflow of foreign currency from the transportation between the third countries to be supplied and the share of the Turkish-flag ships from the transit transportation to be reached 3 million tons.

Sixth Five-Year Development Plan period (1989–1994) has been a period especially emphasizing ship building industry capacity of Turkey. It was expressed that the necessary financial facilities should be supplied for evaluating the ship building industry capacity of Turkey, renewing the merchant marine and meeting the additional ship requirement.

During the sixth plan period it was expressed a study would be prepared which would detect the social, economic and environmental features of the Turkish coasts at industrial, commercial and touristic points, the current harbor capacities, and the potential coasts of the sector suitable for developing.

The Sixth Five-Year Development Plan period (1989–1994) was the period when the privatization studies for harbors started. In this plan period it was aimed at starting for the "autonomic harbor management" application in order to make some of the important foreign trade harbors of Turkey more effective.

In this context it was aimed at making the administrative arrangements in order to privatize the activities at public harbors according to their subject, and applying with the "pilot projects".

8 SEVENTH FIVE-YEARS DEVELOPMENT PLAN (1996–2000)

During the Seventh Five-Year Development Plan period (1996–2000) it was initially expressed "an environment-friendly transportation infrastructure" and also carrying out the transportation infrastructure required for the economic and international relations with the Independent Turkish States for the state's benefits in conformity with the current facilities.

In the plan it was again aimed at – as in earlier plans – increasing the effectiveness, using the current capacities effectively, making the legal and corporate arrangements and infrastructure to direct the domestic transports generally carried out by the road transportation to the maritime transportation.

For the reason that a "Transportation Policy", which was in conformity with the economic and social progress of the state in addition to the integrated and stable structure for the transportation systems, couldn't be determined, it was decided to prepare a "Master Transportation Plan" in the Seventh Five-Year Development Plan (1996–2000).

The privatization at the maritime sector was clearly expressed in the 6th plan period. In the plan it was adopted the privatization programs and control mechanisms suitable for the maritime sector to be carried out. It was aimed at making investments for the maritime sector to be with "Build-Operate-Transfer" model as also in the other investments. Moreover it was decided to improve the programmed investments in the harbors and to carry out new capacities if required **(SPO, 1995)**.

In order to comply with the global maritime trade conditions totally it was pointed out conforming to the maritime policies of the EU and making arrangements for the national regulation about the marine insurance, environment, financial rent, shipping agency regulation and constituting the maritime specialized court. And thus it was aimed at constituting a "dynamic policy" which would follow the global maritime sector closely and make arrangements complying with the growing national and international conditions.

The idea as "the harbor management, which has not been totally completed, to be under the autonomic structure or else to be prepared for the international competence by privatizing was included in the Seventh Five-Year Development Plan (1996–2000).

9 EIGHTH FIVE-YEARS DEVELOPMENT PLAN (2001–2005)

It was predicted that the combine transportation – one of the most importation transportation in the 21st century – would affect also Turkey, which is a transit country, for harbors and the other transportation infrastructures during the Eighth Five-Year Development Plan (2001–2005).

It was aimed at improving, modernizing and increasing the capacities of Turkish harbors according to the "National Harbors Master Plan" completed in 2000 in order to attribute Turkey as a transit lane of the transit transportation **(SPO, 2000)**.

During the Eighth Five-Year Development Plan (2001–2005) it was especially emphasized that the required policies should be followed in order to make transportation services economic and safe, to balance the transportation types in conformity with the requirements of Turkey, to provide the security of life and property during the transportation, to minimize the damages to the environment, to benefit best from the information and technologies.

For the reason that the coastal shipping monopoly has to be expired if Turkey becomes a member of the EU, it was decided that necessary measures should be followed to support the load and passenger ships – carrying out the coastal shipping – for harbor services and fuel in order to direct the load and passenger transportation in Turkey to the maritime transportation. In order to be ready for a possible the European Union competition it was aimed at strengthening the coaster fleet.

It was aimed at making the necessary legal regulation changes to arrange the maritime regulation in accordance with the international regulation, to enable the entrepreneur to acquire and manage the ship by the financial renting, to apply the indirect supports -in force in the international area- for building a new ship.

It was again aimed the harbor management to be under an autonomic structure and to be prepared for the international competition.

It was aimed Turkey -a bridge between Europe and Asia- to become a combine transportation terminal for the transit transportation between these two continents.

It was pointed out the international crude oil and natural gas pipeline investments, which is very important for the maritime sector and will attribute Turkey one of the most important energy distribution center, should be paid attention. And so, Baku-Tbilisi-Ceyhan Pipeline projects, which will transfer the crude oil manufactured in Kazakhstan, Turkmenistan and Azerbaijan in Caspian Basin, to the Mediterranean and than to the world markets by pipeline, was completed in the 8th Plan period.

10 NINETH DEVELOPMENT PLAN (2007–2013)

It is seen that any concrete targets concerning specifically the maritime sector have been determined for the Nineth Development Plan (2007–2013).

The landlocked Turkish Republics including Azerbaijan, Kazakhstan, Turkmenistan, Uzbekistan and Kyrgzistan couldn't reach the Persian Gulf or the Mediterranean because Iran blocks. If Iran still carries on the same policy, it is aimed at transporting the products of the landlocked Turkish Republics over Caspian Sea to Baku and then to the Mediterranean or the Black Sea by the RO-RO.

In order to achieve this target, the mentioned countries will be able to reach to Trabzon and Mersin

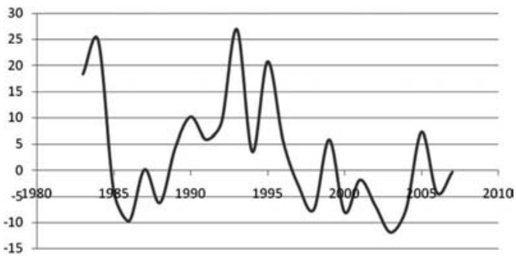

Figure 1. Change of Turkish Merchant Marine Fleet (1980–2007).

in Turkey following the Trans-Asia road and railway projects are completed. So it is aimed at completing the Trans-Asia road and railway projects as soon as possible **(SPO, 2006).**

The transportation between the Turkish Republics as well as the other Middle East countries and the member states of the European Union is carried out mostly over the Ren-Main-Danube Canal and the Black Sea, the Marmara and the Turkish Straits. Moreover, in order to meet the requirements concerning the commercial transportations to be carried out with the countries next to the Black Sea, it is pointed out that;

- The equipment needs of the Turkish harbors in the Black Sea should be supplied,
- Because of the probable circulation at Turkish straits, a computer-aided radar control system should be established to make the circulation safe,
- It should be made investments for affecting the salvage services.

In order to use the Danube-Rhine Canal -opened for circulation in 1992- more effective, the navigation treaties between the Danube States should be completed and the constructions carried out over the river should be ended. In the future, it is expected the Turkish harbors to have share from the great transportation carried out over Danube-Rhine Canal.

11 CONCLUSION AND PROPOSALS

The dwt-based shares of the Turkish Merchant Marine with 7,2 million are as 46,92% for the Bulk Carriers, 20,30% for the Dry Cargo Vessels and 15,51% the Petrol Tankers, respectively. The dwt-based share of the other types of ships is 17,27%.

The division of the tonnage and age groups of the Turkish Merchant Marine as following;

In the fleet with totally 1473 ships and 7.244.062 Dwt; 374 ships with 2.700.763 Dwt are at age group of 0 to 9 years, 275 ships with 601.925 Dwt are at age group of 10 to 19 years, 412 ships with 2.858.223 Dwt are at age group of 20 to 29 years and 412 ships with 1.083.151 Dwt are at age group of 30 years and over.

There have been increases and decreases at dwt share of the Turkish Merchant Marine at 5,7% in 1998 and 1999, at −8,1% in 1999 and 2000, at −1,9% in

Table 1. Change of Turkish Port Activities (Million Ton).

Year	Shipment	Emptying
2000	16,480,210	20,847,595
2001	13,647,620	12,633,778
2002	13,044,511	12,213,078
2003	13,511,217	12,833,551
2004	14,539,714	14,678,638
2005	14,238,305	13,858,655
2006	13,595,664	14,682,817
2007	16,364,074	18,741,552

2000 and 2001, at −6,9% in 2001 and 2002, at −12,0% in 2002 and 2003, at −7,5% in 2003 and 2004, at 7,8% 2004 and 2005, at −4,3% 2005 and 2006 and at −0,2% in 2006 and 2007 (Fig. 1).

37% of the Turkish Merchant Marine are at age group of 0 to 9 years, 8% of are at age group of 10 to 19 years, 40% of are at age group of 20 to 29 years and 15% of are at age group 30 years and over.

In 2007 the Turkish Merchant Marine was composed of 1473 ships, 47% of (693 ships) were registered in the National Registration and 53% of (780 ships) were registered in the International Ship Registration of Turkey(TUGS).

The 10% of dwt share of the Turkish Merchant Marine was registered in the National Registry and the 90% of dwt share was registered in the TUGS; the 14,7% of grt share was registered in the National Registry and the 85,3% of grt share was registered in the International Ship Registration of Turkey(TUGS).

Shares of the most important export items of maritime lines – 67,5 million tons in 2007 – were 10,6% for the Construction Iron, 5,7% for the Feldspar and 4,3% for the Fuel Oil. And shares of the most important import items of maritime lines – 152,3 million tons in 2007 – were 15,6% for the Coal, 14,5% for the Crude Oil and 10,9% for the Junk.

The foreign trade transportation of Turkey in 2004 was totally 173,6 million tons. The 151,8-million tonpart of those loads i.e. 87,4% was carried out by maritime transportation **(COS, 2006).**

Although it was aimed at transporting at least 50% of the Turkish foreign trade goods in the First 5-Year Development Plan period, this aim has not been achieved yet **(COS, 2008).**

On the The foreign trade transportation share with the Turkish-Flag ships of Turkey in 2005 was 25,3% for import and 18% for export **(Table, 1)**. Contrary foreign-flag ships' share was 74,7% for import and 82% for export **(Table, 2)**. The share of national marine was just 23% for the foreign trade transportation in 2005, and the freight paid to the foreign-flag ships went beyond 3 Billion Dollars per year.

For the reason Turkey is too late for acquiring the Turkish-flag cruise, ferry and passenger ship, Turkey couldn't benefit from the growing cruise tourisme sufficiently **(Ucisik&Kadioglu, 2001).**

Since the guideness and tug services are privatized, the service quality increased and prices are balanced in accordance with the competition.

Table 2. Change of Turkish Merchant Marine Fleet for Turkish Foreign Trade (Million Ton).

Year	Turkish Flag	Foreign Flag
1998	33,6	66,4
1999	31,2	68,8
2000	32,1	67,9
2001	34,6	65,4
2002	36,1	63,9
2003	30,3	69,6
2004	25,3	74,7
2005	25,1	74,9
2006	23,2	76,8
2007	17,7	82,3

The target about renewing the Turkish Merchant Marine expressed in the Second, Third, Fifth and Eighth Plan periods has not been achieved yet.

The studies about renewing and strengthening the Turkish merchant marine still continue.

Although there are vast opportunities in Turkey, the coastal shipping is not carried out enough. Old and small coaster fleet is less important for the load transportation.

It is aimed at renewing and strengthening the ships carrying out the international transportation and especially the coaster fleet.

The target about the harbor management to be under the autonomic structure or to be prepared for the international competition by privatization has not been achieved completely.

The container transports in the Turkish harbors were expressed mostly in the Fifth Plan period. However the target about making investments for the new container terminals was included just in the Seventh Plan period.

Until the 2008 global crisis, it was the golden age for Turkey and the World at ship building. There are full of orders in the whole private-sector shipyards in Turkey till 2010. Turkey started to build chemical tanker, container ship, tug and similar ships at about 30000 DWT for Germany, Italy, Spain, France, Denmark, Sweden, Norway, Holland, Russia and England. Because of the global crisis in 2008 Turkish shipyards were affected in a negative way.

In Turkey the number of the training institutes to educate a seafarer and the graduated students of those institutes has substantially increased. And also first private maritime university of Turkey was founded.

The important part of the structural problems of the maritime sector blocking the international competition has been solved.

A safe and detailed database has been established for the maritime sector.

In 1987 there were 21 harbors handling domestic and foreign trade goods at the public administration. Moreover totally 69 harbors -6 of them were operated by the industrial bodies and 32 small harbors and seaports were operated by the municipalities and the other bodies- were active.

There are 160 harbors and seaports in Turkey in 2008 that 6 of them are operated by the TDİ (Turkish Maritime Organizations) and 6 of them are operated by the TCDD/Turkish State Railways. If we examine in terms of operated bodies, there are 25 public harbors, 27 municipality harbors and 108 private harbors **(Kadioglu & Bas, 2008).**

For the reason that the Turkish harbors couldn’t follow the technologic developments, the infrastructure is not adequate and the railway connections which will integrate into the harbors are not sufficient, Turkey couldn’t benefit from the transit transportation enough.

In 2007 it is observed that the transit transportation became more important when the Baku-Tbilisi-Ceyhan (BTC) pipeline which has been entered into service since July 2006 and has transferred the Azerbaijani petrol first to Ceyhan by the pipeline and then especially to Europe and the Middle Eastern States by the maritime lines. 210.352.000 barrels of petrol were transferred by the BTC pipeline in 2007.

288.083.916 ton loads were handled in harbors and seaports of Turkey in 2007. Division as following:

– 67.597.739 tons of export including 23,4%
– 152.313.601 tons of import including 52,9%
– 35.105.626 tons of freight including 12,2%
– 33.066.950 tons of transit including 11,5%.

The Turkish ship building industry is one of the sectors improving quickly.

In Turkey the ship building capacities in 1987 were 25.000 DWT – the largest one – in one-piece for military purpose, 75.000 DWT for Turkish Shipping Industry of public and 30.000 DWT for the private sector. The iron working capacities of those shipyards were 117.380 tons per year and the ship building capacities were 306.060 DWT per year.

The number of the shipyards was 27 in 1982 and today there are 84 active shipyards from the Mediterranean to the Black Sea by detecting new building areas and modernizing the facilities. In 2013 the number of shipyards will be 140 together with the current projects **(SPO, 2006)**.

The Turkish ship building industry has the possibility and capacity as 10 Million DWTs for maintenance, 1 Million 800 thousand DWTs for new ship building, 600 thousand tons for steel working and up to 80 thousand DWTs for new ship building.

The Turkish shipyards having the capacity and employment increase especially for the last 3 years was ranked 23rd in 2002, reached to the 8th rank in 2006 by the 1,8 million-DWT ship and yacht order and reached to 6th rank by the 239 ship and yacht order with 3.05 Million DWT. The sector breaking records on the amount and tonnage of ships built in export in 2008 was at top 5 at ship building order market **(COS, 2007)**.

Now Turkish shipyards are at number 1 at small-tonnage chemical tanker building and at number 3 at mega yacht building. Medium and small-sized ship projects have been sent to Turkey especially since 2002.

The studies about conforming to the European Union still continue **(Kadioglu & Deniz 1997)**.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

14.8 The influence of organic polymer on parameters determining ability to liquefaction of mineral concentrates

M. Popek
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: When the wet granular materials lose their shear strength they flow like fluids. This phenomenon is called liquefaction. The liquefaction can be prevented by means of limiting the moisture content of cargo by introducing the safety margin. Cargoes, which may liquefy shall only be accepted for loading when the actual moisture content of the cargo is less than its Transportable Moisture Limit (TML). It has been recognized that in some cargoes, moisture can gravity drain towards the bottom of the hold. The resulting much wetter bottom layer may therefore be prone to liquefaction and provoke instability of the entire cargo.

To prevent sliding and shifting of ore concentrates in storage a biodegradable materials are added to the ore. The polymer materials absorb water from the ore particle's pores and the moisture content goes down. In consequence polymer materials may prevent drainage of the water from the ore particle's pore.

1 INTRODUCTION

Bulk shipping has been used for many years to reduce the cost of sea transport and the transport of bulk cargoes is a vital component of international trade. Such trades require a sufficient volume of cargo suitable for bulk handling and hence justify a tailored shipping operation. The five major dry bulk cargoes are coal, mineral concentrates, grain, bauxite and phosphate rock, and each year the trade in bulk increases (Roberts M. & Marlow P. 2004).

In recent years, bulk carriers have been identified with the high risk of catastrophic structural failure and foundering, and with heavy loss of human life. Several risk factors have been identified that had significant, independent effect upon the likelihood of a bulk carrier foundering. Ore concentrates and other similar fine-grained materials transported by sea belong to hazardous materials when are considered as bulk cargoes (materials MHB). This type of cargoes is transported in a wet state.

Excessively wet cargo can pass into liquid state in sea transport conditions (Zhan M. 2005, Shitharam T. G. 2003). According to the Code of Safe Practice for Solid Bulk Cargoes (BC Code) (International Maritime Organization 2004), deterioration or loss of ship's stability is one of three basic hazards, which are bound with sea shipment of ore concentrates and other fine-grained cargoes. Too high humidity of cargo leading to its liquefaction may cause shift of the cargo and in consequence ship's heel and even its capsizing and sinking.

The International Maritime Organization (IMO), recognising that some losses had occurred due to improper loading, issued a code of practice for these operations. The probability of a hazard developing into an undesirable consequence is focus of safety management and safety regulation. The recent publication of recommendation guidelines for cargo–handling operations and the amendments to the International Convention for the Safety of Life at Sea contribute to the decrease the possibility of occurrence the liquefaction during sea transportation (International Chamber of Shipping1999, BLU Code London, (2004)).

To better illustrate liquefaction mechanism three-phase structure of ore concentrates and similar materials is considered, which consist of solids (mineral grains), water and air.

Mineral grains are very small; they are from 0,001mm to several millimeters large. Disintegration level and percentage of particular size fraction may differ depending on concentrate type.

In three – phase structure air and water fill the pores between mineral grains. The inter-grain pores are contracted in sea transport conditions due to ship rolling and vibration. The air, permeability coefficient of which is about 500 times greater than that of water, first escapes, thus full water saturation of pores is affected.

Full compressive stress is thus applied to the incompressible water in the pores between mineral grains which causes drop of inter-grain friction, i.e. ore liquefaction and in consequence possible shift of cargo (Michałowski & others 1995).

The possibility of instability because of liquefaction of bulk cargoes such as mineral concentrates has been recognized for some time. BC Code includes several provisions aimed to prevent the movement of bulk cargoes either by sliding or liquefaction.

Moisture content allowing to passing of a bulk cargo from solid into liquid state is called critical moisture content. One of its possible measures is Flow Moisture

Point (FMP). On its basis permissible moisture limits for shipment conditions are determined. Transportable Moisture Limit (TML) is such moisture content at or below which a loose cargo can be transported in bulk on ships without danger of passing of the cargo into liquid state. Its usually calculated as 90% of FMP. The possibility of instability because of liquefaction of bulk cargoes such as mineral concentrates has been recognized for some time. Many cases are reported of large heel of a ship or even her sinking due to cargo liquefaction. A cargo, which is liable to liquefaction, must be sufficiently fine grained (so that permeability is sufficiently low) and have a high enough initial moisture content:

For cargoes with permeability so low that virtually no moisture redistribution occurs during voyage, the initial moisture content needs to be below the transportable moisture limit so that the whole cargo does not liquefy as a result of the ship's motion during heavy weather.

For cargoes that are relatively free draining, redistribution occurs with moisture from the upper levels of the cargo draining towards the base. Unless efficiently drained the bilges, this water saturates the bottom levels of the cargo and liquefaction could occur with cargo shifting during heavy rolling motions (Eckerley J.D. 1997).

These cargoes, prone to liquefaction, should never be carried without checking the moisture content. The Code of Safe Practice for Solid Bulk Cargoes lays down that a certificate stating the relevant characteristics of the material to be loaded should be provided at the loading port, incorporating also the transportable moisture limit. The cargoes which may liquefy shall only be accepted for loading when the actual moisture content of the cargo is less then its Transportable Moisture Content and refused if the analysis reveals that it's moisture content is too high. The Code provides information how the moisture content of ores concentrates can be tested and assessed.

For liquefaction the cargo needs to have permeability low enough that excess pore pressures cannot dissipate before sliding occurs. This condition is controlled by the material's grain size distribution, and Kirby expressed this in requirement that 95 percent or more of the cargo should be coarser than 1mm to prevent liquefaction. In soil mechanics literature the requirement is usually expressed as 0,006 mm < d10 < 0,3 mm for liquefaction to be likely, where d10 represents the particle size for which only ten percent by mass of the material is finer (Eckerley J.D. 1987).

A large group of organic polymers fined use in the mineral industry with the specific function [Bulatovic 1997]. Particularly attractive are the new materials based on natural renewable resources, preventing further impact on the environment.

Starch is non-expensive biopolymer available from annually renewable resource. It is totally biodegradable in a wide variety of environments and allows the development of totally degradable products. Starch can be found in plants as a mixture of two polysaccharides: amylase, the nearly linear polymer consisting of α – (1, 4)-anhydroglucose units, and amylopectin, a group which is able to undergo substitution reactions and C-O-C linkage responsible for the molecular chain braking. The OH group has a nucleophilic character and by reaction with different reagents it is possible to obtain a series of compounds of modified properties. Chemical and physical properties of starch have been widely investigated due to its easy to be converted into a thermoplastic and then be used in different applications (Tudorachi N. & others 2006). Starch based blends present enormous potential to be widely used in environmental fields, as they are totally biodegradable, inexpensive (when compared to other biodegradable polymers). The material containing starch gets destroyed when exposed to environmental factors, since due to starch hydrolysis its structure becomes weaker, and after some time, under certain conditions, synthetic polymers contained in the product also undergo decomposition.

The purpose of this work was investigation on possibility of using biodegradable thermoplastic materials as absorbers moisture. To prevent sliding and shifting of ore concentrates in storage materials composed of starch, cellulose and polycaprolactone are added to the concentrates. The properties and the processing procedures of biodegradable starch – based thermoplastic blends, like starch/polycaprolactone, starch/cellulose have been already reported (Demirgoz & others, 2000).

2 EXPERIMENTAL PROCEDURES

2.1 *Material*

The iron concentrate was used for the tests.

It is a product of a gravimetric separation of large mineral particles. The iron concentrate is a fine material which is empirically judged as "which may liquefy if shipped above the TML".

Following polymer materials were tested: polymer material Y (made of thermoplastic starch and cellulose derivatives from natural origin) and polymer material Z (made of starch and policaprolactone).

The used polymer materials are classified as a low environmental impact product.

Based on the results of estimation the ability to absorb of water by polymers materials it can be said that polymer material Y absorbs more water then polymer material Z. The equilibrium absorption of polymer Y is reached in 48 hours. The time taken to reach equilibrium water content in polymer Z is shorter – about 18 hours.

Water uptake is affected by the type of polymer. The time required to reach equilibrium water uptake is lower for blend containing starch and polycaprolactone then for blend containing starch and cellulose (Popek M. 2005).

The samples of polymer materials were in granular form. The experiments were conducted for samples of concentrate: without polymer materials and for mixtures contain 98% concentrate and 2% of polymer materials.

The course of grain size distribution curves indicates that all the tested samples are susceptible to liquefaction in sea transportation conditions as in each case the content of grains smaller then 0,3 mm is greater then 10%. The content percentage values of the grains (of the size below 0,3 mm) in concentrate without polymer is 76,9%. In mixtures of concentrate and polymer materials the contents of particles with a diameter smaller than 0,3 mm are negligible smaller and amount 76,0% for mixture with polymer Y and 76,1% for mixture with polymer Z. the results of grain size analysis indicate that polymers do not significantly change grain size distribution. This is the reason why all tested samples may liquefy.

2.2 *Methods*

Following tests have been carried out:

- Estimation of TML:
  The International Maritime Organization approved, in the Code of Safe Practice for Solid Bulk Cargoes the following assessment methods of safe moisture content in the cargoes: Flow Table Method, Japanese Penetration Method and proctor/Fagerberg Method. The evaluation of FMP was performed with the use of the Proctor Fagerberg Test. Proctor/Fagerberg Method is recommended for evaluation of some fine-grained bulk cargoes. The sample was consolidated by 25 drops of rammer from 0,2 m height in the measuring cylinder, layer by layer, repeating the procedure 5 times and finally weighing the cylinder with the moist sample. Then volumetric density of the wet concentrate γ_{0b} and of the dry consolidated concentrate γ_{0bjs} were calculated and a consolidation curve $\gamma_{0bjs} - f(w)$ drawn, where "w" stands for moisture content percentage in relation either to wet concentrate weight. TML was determined from a cross point of the void ratio curve and a line of 70% degree of saturation, theoretically calculated.
- Permeability of concentrates:
  The permeability is the rate at which water under pressure can diffuse through the voids in the mineral concentrates. These materials are permeable to water because the voids between the particles are interconnected. The degree of permeability is characterized by the permeability coefficient k, also referred to as hydraulic conductivity.

  According to the classification of soils, based on their coefficient of permeability, mineral concentrates are the materials with the low degree of permeability. The permeability of mineral concentrates depends primarily on the size and shape of grains, shape and arrangement of voids, void ratio, degree of saturation, and temperature.
- Measurement of the cohesion and internal friction angle:
  The estimation of cohesion and internal friction angle were performed in the direct shear apparatus by carrying the shearing with the help of lower and upper part of displacing box containing the tested concentrate. In the experiment the samples were compacted in a dry state. The moisture content corresponds to the TML value estimated in Flow Table Test.

  In the experiments (estimation of the permeability and the cohesion and internal friction angle) the samples were compacted. The consolidation conditions (in the holds) were simulated by using vertical loads: 0 N, 98 N, 196 N, 294 N and 490 N, what corresponds to the normal stresses: 0, 1,532 *104 N/m^2, 3, 0645 *104 N/m^2, 4,589 *104 N/m^2, 7,659 *104 N/m^2 respectively. The test without any stress corresponds to the stress in the hold during the loading. Increasing values of normal stresses represents the changes in the bulk cargoes during the sea transportation.

3 RESULTS AND DISCUSSION

3.1 *Estimation of TML*

The results obtained by using Proctor/Fagerberg test are shown in Figures 1–2. The figures show Void Ratio as a function of net moisture content by volume. In each figure, the ordinate and abscissa denote void ratio and net moisture content by volume, respectively. The black circles indicate the measured data. The straight line corresponds to degree of saturation 70% theoretically calculated. TML was determined from a cross point of the experimental curve and a line of 70% degree of saturation.

The obtained results are presented in Table 1.

Despite the presence of polymer in tested concentrate, the values of estimated TML are similar, because liquefaction is tightly related to the grain size contents.

3.2 *Permeability*

The results of permeability test are presented in Table 2.

The compaction modifies permeability of samples by decreasing the voids available for flow and reorienting particles. Based on the results the effect of different

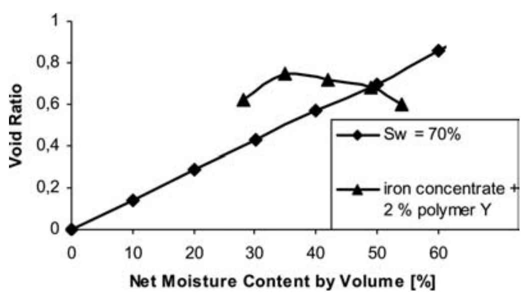

Figure 1. Compaction curve for iron concentrate + 2% polymer Y.

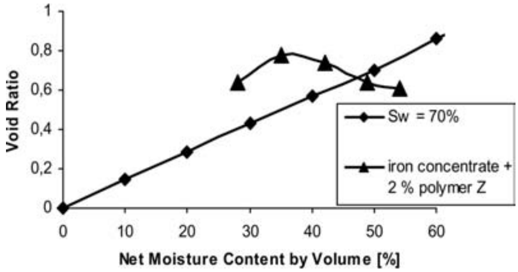

Figure 2. Compaction curve for iron concentrate + 2% polymer Z.

Table 1. Transportable Moisture Limit determined by Proctor Fagerberg test.

Sample	Specific gravity of solid	Transportable Limit of Net Moisture Content by Volume	TML
Iron concentrate + 2% polymer Y	4,98	49%	9,02
Iron concentrate + 2% polymer Z		47,5%	8,7

Table 2. Results of permeability test.

	Permeability coefficient k [m/s]	
Normal stress [N/m^2]	Iron concentrate + 2% polymer Y	Iron concentrate + 2% polymer Z
0	$14{,}0*10^{-3}$	$15{,}2*10^{-3}$
$1{,}532*10^4$	$8{,}5*10^{-3}$	$9{,}2*10^{-3}$
$3{,}064*10^4$	$7{,}1*10^{-3}$	$8{,}8*10^{-3}$
$4{,}589*10^4$	$5{,}2*10^{-3}$	$7{,}5*10^{-3}$
$7{,}659*10^4$	$3{,}5*10^{-3}$	$5{,}15*10^{-3}$

compaction of the samples on the permeability was observed. The maximum values of permeability coefficient k were achieved for samples without any stress. The increase of consolidation force caused decreases the value of the permeability coefficient. The ability to permeability of mixtures is related to the composition of the polymer material. In all cases, for samples with polymer material Y, the higher decrease of permeability was obtained.

3.3 *Cohesion and internal friction angle*

The changes of internal friction angle as a function of moisture content are presented in Figures 3–4.

As a result of performed test it can be said that internal friction angle reaches minimum value when

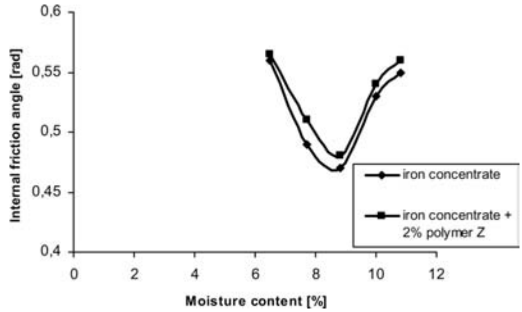

Figure 3. Internal friction angle for iron concentrate + 2% polymer Y.

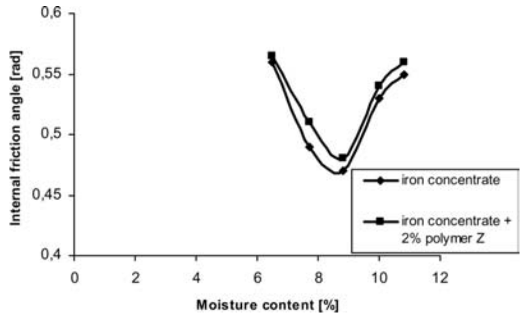

Figure 4. Internal friction angle for iron concentrate + 2% polymer Z.

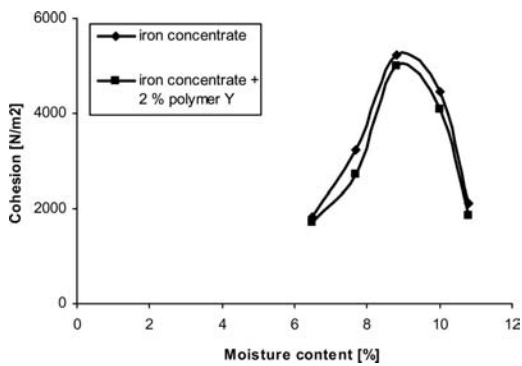

Figure 5. Cohesion for iron concentrate + 2% polymer Y.

moisture content is chosen to TML. The presence of polymer material in tested sample influences on the value of internal friction angle. In each case the values are higher than those for sample without polymer material.

The cohesion as a function of moisture content are presented in Figures 5–6.

The apparent cohesion does not occur in dry materials with pores entirely filled with air nor in moist materials having pores entirely filled with water. In all samples cohesion increases with the increasing content of water and it reaches a maximum value with moisture approaching the TML and then it goes down. The presence of polymer material in tested sample

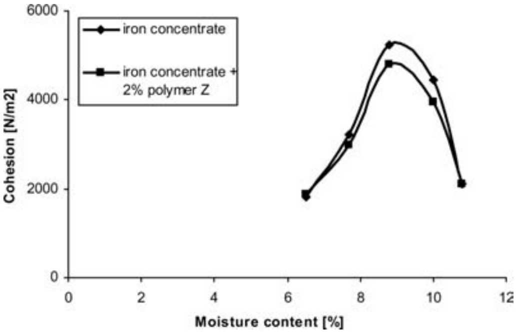

Figure 6. Cohesion for iron concentrate + 2% polymer Z.

significantly changes values of cohesion. Decreasing values of cohesion, for each moisture content, is observed.

4 CONCLUSIONS

The conclusion is based on the measurement of the TML, cohesion and permeability of the materials.

The comparison of the TML values confirms that the correlation between the grain content and TML values occurs.

The presence of polymer material in tested sample influences on the values of cohesion and internal friction angle but the extreme values are reached at the same moisture content.

The nature and magnitude of compaction in fine – grained materials such as mineral concentrates significantly influences their mechanical behavior. Increasing values of normal stresses tends to reduction the degree of permeability.

In consequence, polymer materials prevent drainage of the water from the particle pore, sliding and shifting of ore concentrates in storage. These polymer materials can be used as absorbers of water from mineral concentrates, before the transportation by sea. These materials are particularly attractive because they are based on natural renewable resources, which are environmentally friendly.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

14.9
Application of thermal analysis and trough test for determination of the fire safety of some fertilizers containing nitrates

K. Kwiatkowska-Sienkiewicz & P. Kałucka
Gdynia Maritime University, Department of Chemistry and Industrial Commodity Science, Poland

ABSTRACT: The studies on how a fire on board accidents may be prevented have been actively carried out at both the national and international levels. This paper provides an outlook on fire safety assessment concerning nitrates fertilizers in sea transport. The investigation was aimed at comparison two methods of classification and assignment to a packing group of solid fertilizers of class 5.1 of International Maritime Danger Goods Code. First research was conducted in accordance with the test method described in the United Nations Recommendations on the Transport of Dangerous Goods, Manual of Test and Criteria, Part III, 34.4.1 “Test for oxidizing solids”. The second method was the differential thermal analysis (DTA) where the basis was the determination the temperature change rate during thermal reaction. According to two used tests, the investigated fertilizers belong to 5.1 class and require to packaging group III of the International Maritime Danger Goods Code. The DTA method gives more quantitative information about fire risk on the ship than method recommended in International Maritime Danger Goods Code.

1 INTRODUCTION

The range of materials, which must be transported by sea and stored, is gradually increasing. Today we need observe more consideration of aspects of transportation of large quantity of dangerous goods. The term dangerous is limited to substances which have the potential to cause major accident risk from fire, explosion or toxic release. Including also oxidizing and explosives materials, which during transport might be initiated by fire, impact, resulting from badly packed or was out of specification explosives. In the International Maritime Dangerous Goods Code the information concerning various aspects of sea handling of hazardous materials is contained. Official regulations and supplementary documentation of the hazardous properties of materials can be found in this code. It is an important source of basic information and a guide to shipping of hazardous goods for a ship staff.

Oxidizers are dangerous goods in accordance with International Maritime Dangerous Goods Code (IMDG Code), belong to 5.1 class, they are not necessarily flammable, but able to intensify the fire by emission oxygen. Oxidizers may be elements, acids, or solid substances (e.g. nitrates salts). Some oxidizing substances have toxic or corrosive properties, or have been identified as harmful to the marine environment. They will react in contact with reducing reagents. Hence oxidizing agent will invariably accelerate the rate of burning of combustible material. The National Fire Protection Association in United Stated classified oxidizing substances according the stability [Burke, 2004]:

Class 1 – Solid or liquid that readily yields oxygen or oxidizing gas or that readily reacts to oxidizer combustible materials.

Class 2 – Oxidizing material can cause spontaneous ignition when contact with combustible materials.

Class 3 – Oxidizing substances that can undergo vigorous self sustained decomposition when catalyzed or exposed to heat.

Class 4 – Oxidizing articles that can undergo an explosive reaction when catalyzed or exposed to heat, shock or friction.

Among the fertilizers mentioned in the IMDG Code the most dangerous are nitrates(V), belong to oxidizers of class 5.1 of danger goods and ammonium salts [IMDG Code]. Pure ammonium nitrate, the base of fertilizers, belong to compounds transported in limited quantities (UN 0222 – ammonium nitrate, with more than 0,2% combustible substance) Ammonium nitrate UN 1942 with not more than 0,2% total combustible substances including any organic substance calculated as carbon during transport the temperature of material should not be above 40°C. Do not ventilate this cargo.

Ammonium nitrate based fertilizers UN 2067, UN 2071,UN 2067 may transported in bulk. Fertilizers: potassium nitrate – UN 1486, sodium nitrate UN 1498 and sodium and potassium nitrate mixtures UN 1499, calcium nitrate UN 1454 may be also transported in bulk [BC Code]. Nitrates fertilizers are highly hygroscopic and will cake if wet. They belong to cargo group A and B (Group A consists of cargoes which may liquefy if shipped at a moisture content in excess of their transportable limit. Group B consists of cargoes which possess chemical hazard which could give rise to dangerous situation on the ship) [Appendix A and B BC Code, 2001].

A major fire aboard a ship carrying these materials may involve a risk of explosion in the event of contamination by combustible materials or strong confinement. An adjacent detonation may also involve a risk of explosion. During thermal decompose nitrate fertilizers giving toxic gases and gases which support to combustion. Dust of fertilizers might be irritating to skin and mucous membranes.

Classification of oxidizing substances to class 5.1 is based on test described in the IMDG Code and Manual of Tests and Criteria [UN Recommendations Part III]. In this test, the investigated substances were mixed with cellulose, which is a combustible material, in ratios of 1:1 and 4:1, by mass, of substance to cellulose. The mixtures were ignited and the burning time was noted and compared to a reference mixture, in ratio 3:7, by mass, of potassium bromate(V) to cellulose.

The assignation criteria to the packaging groups are based on a physical or chemical property of goods. There are at present no established good criteria for determining packaging groups. (To packaging group I belongs substances great danger, II – medium danger, or III, minor danger).

If a mixture of test substance and cellulose burns equal to or less than the reference mixture, this indicates that the combustion of the combustible material (cellulose) is enhanced by the test substance and the test substance has oxidizing (fire enhancing) properties and is classified in class 5.1. This also means that oxidizing substance is assigned to a packing group III (if the criteria of packing group I and II are not met). Next the burning time is compared with those from the packing group I or II reference standards, 3:2 and 2:3 ratios, by mass, of potassium bromate(V) and cellulose. Any substance which, in both the 4:1 and 1:1 sample-to-cellulose ratio (by mass) tested, does not ignite and burn, or exhibits mean burning times greater than that of a 3:7 mixture (by mass) of potassium bromate(V) and cellulose, is not classified as class 5.1.

Using these criteria we test a big mass sample of component which involve larger volumes of toxic gases, as opposed to a differential thermal analysis, where the basis is the determination the temperature change rate during thermal decomposition.

Using differential thermal analysis (DTA) we can registration quality and quantity changes during dynamic heating of investigated materials in time.

The self-heating or thermally explosive behavior of individual chemicals is closely related to the appearance of thermogravimetry-differential thermal analysis (TG-DTA) curve with its course.

In previous examinations of mixtures of oxidizers with cellulose and flour wood [Michałowski, Barcewicz 1997, Michałowski Barcewaicz 1998, Michałowski, Rutkowska, Barcewicz 2000, Kwiatkowska-Sienkiewicz et al 2006, Kwiatkowska-Sienkiewicz 2008] the temperature change rates [°C/s] were calculated into 1 milimole of an oxidizer and tested oxidizing substances were blended with combustible substance in mass ratio 5:1.

According to later experiments not classified to class 5.1 any substances which temperature change rate are lower than 0,2 [°C/s].

To packaging group III should be assigned substances, which during thermal analysis mixtures oxidants with cellulose, the temperature change rate values are between 0,2 to 1,4 [°C/s].

To packaging group II should be assigned substances blended with cellulose of with the temperature change rate values are between 1,4 to 5,0 [°C/s].

To packaging group I belong of mixtures oxidizes with cellulose which temperature change rate values exceed 5,0 [°C/s].

Later and now in experiments used cellulose as combustible material. Cellulose belongs to polysaccharides, develop free radicals on heating. The free radicals in cellulose thermolysates is cellulose variety dependent. The generation of free radicals on heating is time and temperature dependent whereas in termoanalitical studies exposure to heat is for relatively short time. All polysaccharides (e.g. starch) during heating generated free radicals [Ciesielski, Tomasik 1998, Ciesielski, Tomasik, Baczkowicz 1998].

In practice, during long transport combustible materials and commodities containing polysaccharides we can observe self-heating effect, specially, if polysaccharides are blended with oxidizers. Free radical exposed during thermal reaction polysaccharides mixed with nitrates (V) (nitrates(V) belongs to 5.1 class dangers goods), gives possibility self-heating and self-ignition chemical reaction.

In these paper fertilizers, containing sodium, potassium, calcium and ammonium nitrates, blended with cellulose was investigated.

This examinations whereas basing on potassium bromated (V) blends with cellulose (in mass ratio 2:3 and 7:7) as a standard shows that class 5.1 includes substances which temperature change rate was greater than temperature change rate of mixture of potassium bromated (V) with cellulose, in mass ratio 3:7 – 0,96 [°C/s].

To the III packaging group should be assigned substances, which during thermal analysis mixtures oxidants with cellulose, the temperature change rate values are between 0,96–1,82 [°C/s].

II packaging group involves crossing value of the temperature change rate under 1,82 [°C/s].

In this paper we concerned on comparison two methods of assignation to class 5.1 and classification to packing groups. The first one is recommended by United Nations [UN Recommendations] and second one, differential thermal analyze is using in chemistry.

Table 1. Determination risk of fire oxidizers/fertilizers according to Manual Test and Criteria IMDG Code.

		Burn rate [cm/min.]		Proposed	
Oxidizer	Sample to cellulose.	Sample	Standard	Class IMDG	Pacaging group
Ammonium nitrate fertilizer (30% N)	1:1	1,38	0,83	5.1	III
	4:1	1,08			
Nitro-chalk fertilizer (27,5% N)	1:1	0,93	0,83	5.1	III
	4:1	0,20			
Calcium nitrate based fertilizer (15% N)	1:1	0,92	0,83	5.1	III
	4:1	0			
Potassium nitrate based fertilizer (14% N)	1:1	2,18	0,83	5.1	III
	4:1	0			
Sodium nitrate (V) (p.a.)	1:1	2,71	0,83	5.1	III
	4:1	0			
Potassium bromate	2:3	10	10	5.1	II
(V) (p.a.) (standard)	3:7	0,83	0,83	5.1	III

2 EXPERIMENTAL

Determination according to IMDG Code and UN Recommendations test and DTA method were carried out using the same blends oxidants/fertilizer and cellulose.

The following substances were blended with cellulose in mass ratio 1:1 or 1:4

- sodium nitrate (V) pure for analysis,
- ammonium nitrate based fertilizer with 30% nitrogen,
- nitro-chalk with 27,5% nitrogen,
- calcium nitrate based fertilizer with 15% nitrogen,
- potassium nitrate based fertilizer with 14% nitrogen,
- as reference material – potassium bromate(V) pure for analysis blended with cellulose in mass ratio 3:7 and 2:3.

In experiments used microcrystalline cellulose, grade Vivapur type 101, particle size $>250\,\mu$m (60 mesh), bulk density 0.26–0.31 g/ml.

Mean burn time of trials mixtures fertilizes and cellulose are presented in Table 1.

Chemical reaction course during the heating can be investigated by means of differential thermal analysis (DTA) method. Using thermal analysis (DTA),

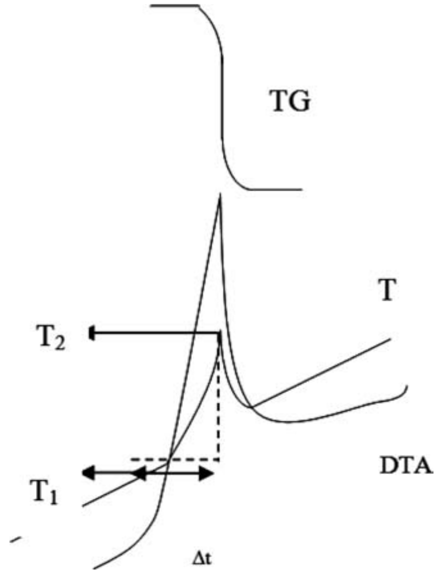

Figure 1. Self – ignition effect monitored by DTA method [Kwiatkowska-Sienkiewicz, Barcewicz 2001].

the changes of mass, temperature and heating effects curves are recorded.

Thermal decomposition with self-ignition effect is demonstrated in Fig. 1.

The following outputs were recorded during measurements using DTA method.

- T – the temperature change curve which is a straight line till the mixture flash point is reached, with a district peak in the self-ignition region, especially during reaction of very active oxidizers,
- DTA curve – gives information about heat effects,
- TG curve – of mass change during the reaction, beginning of self-ignition process – T_1, maximum of self-ignition reaction – T_2, maximum temperature increase: $T_2 - T_1 = \Delta T$, temperature change time (from T_1 to T_2) Δt,

The temperature increase value was determined from the temperature change curve T on the basis of its deflection out of the straight line, in the peak region. On the ground of the above mentioned data following parameters could be calculated. The temperature change rates [°C/s] were calculated by dividing the temperature increase (ΔT) by the time of self-ignition effect (Δt), counted into 1 g of a fertilizers/oxidizers. At first pure oxidants and fertilizers were tested. Then mixtures of fertilizers with cellulose and oxidizers substance with cellulose were tested. Thermal treatment of pure oxidizers or the blends were heated from room temperature to 500°C. The procedure was run in the air under dynamic condition. The rate temperature increase was 10°C/min. Ceramic crucibles were taken. Paulik-Paulik-Erdley 1500 Q Derivatograph (Hungary) was used. The measurements were carried out three times. Decomposition initiating temperatures

Table 2. Thermal decomposition oxidizers/fertilizers and his blends with cellulose using DTA method.

Oxidizers	Sample to cellulose	Ignition temperature [°C] Oxidizer	Ignition temperature [°C] Ox. – cell.	Temperature change rate [°C/s] Ox.	Temperature change rate [°C/s] Ox. – cell.	Egzo + Endo-reaction
Ammonium nitrate based fertilizer (30% N)	1:1	335	205,4	1,67	1.68	+
	4:1		211,7		1,68	+
Nitro-chalk fertilizer (27,5% N)	1:1	338	197,3	0,5	1,7	+
	4:1		218,3		1,74	+
Potassium nitrate based fertilizer (14% N)	1:1	–	*	–		
	4:1	*	315,3		0,95	–
Sodium nitrate (V) (p.a.)	1:1	–	320	–	1,16	+
	4:1	*	326		1,44	+
Potassium bromate (V) (p.a.) (Standard)	3:7	455	329,3	2,6	0,96	+
	2:3		190		1.82	

* – (not observed ignitron until 500°C)
Ox. – oxidizer/fertilizer
cell. – cellulose

Table 3. Assignment of the fertilizers to the packaging group based on temperature change rate.

Name of the fertilizer	Temperature change rate [°C/s]	Assigned packaging group	Proposed class of IMDG Code
Ammonium nitrate based fertilizer (30% N)	1,68	III	5.1
Nitro-chalk fertilizer (27,5% N)	1,74	III	5.1
Potassium nitrate based fertilizer (14% N)	0,96	III	5.1
Sodium nitrate (V)	1,44	III	5.1
Potassium bromate (V) (Standard)	0,96 ÷ 1,81	III	5.1

of the compounds, and his blends with cellulose were read from the recorded curves.

The temperature change rates [°C/s] were calculated from the curves DTA and T by dividing the temperature increase by the time of self-ignition effect, calculated into 1 g of an oxidizer or multicompound fertilizer.

3 RESULTS

The results of performed thermal reactions of oxidizers/fertilizers and cellulose are presented in Tables 1 and 2.

On the basis of results of the test described in Manual of Test and Criteria all examined fertilizers, according to IMDG Code, belong to class 5.1 of Dangerous Goods and require packaging group III.

The results of second method of performed thermal reactions between cellulose and selected fertilizers are presented in Tables 2 and 3. Blends of potassium bromate(V) and cellulose in mass ratio 3:7 and 2:3 are the standards in classification using differential thermal analyses tests (we used the same standards like in Manual Test recommended by IMDG Code).

The ignition temperature and temperature change rate make it possible to assess packaging group of investigated fertilizers, belong to class 5.1 of danger goods.

The blends of fertilizers and cellulose had lower ignition temperature then pure oxidizers. Hence those fertilizers will invariably accelerate the rate of burning with combustible materials. Pure potassium and sodium nitrates, high ionic compounds, had thermal decompose in higher temperatures than 500°C, but the mixtures with combustible material – cellulose were decomposed in temperature about 320°C. All blends fertilizers and cellulose decomposed in lower temperatures than pure oxidizes.

During reactions observed generally exothermic processes and weight losses. It's very dangerous in shipping, especially of bulk cargo. Fertilizers containing nitrates and ammonium salts, during fire on the boat, lost stowage mass about 1/3 to ½.

The results differential thermal analyze suggest similar effects like in the tests recommended by IMDG Code; all investigated fertilizers belong to 5.1. class of dangerous goods and require to packaging group III.

After comparison these two methods of assignation to class 5.1 and packaging group's data thermal analyze gives quantitative information about thermal effects (melting, self-heating, self-ignition) and loss mass during heating. During Manual Test (according IMDG Code) we have only qualitative data burning time of blends oxidizers with cellulose. In Manual Test was use big probe – 30 g blends of oxidizer and cellulose, in DTA method only – 300 ÷ 500 mg.

Differential thermal analyze is objective chemical method which could make it possible to determine the criteria of assignment of oxidizers to packaging groups, required for sea transport. Data DTA method gives more information about fire risk assessment that Manual Test recommended by IMDG Code.

4 CONCLUSION

Manual Test recommended in IMDG Code informs only qualitative about burning time special trial form of oxidizer – cellulose blends.

The comparison two methods of classification and assignment to a packing group of solid substances of class 5.1 of IMDG Code indicate, that differential thermal analyze (DTA method) gives objective, quantitative information about fire risk on the boat.

Using this method, during heating we can registration changes of temperature, loss mass, melting point temperatures mixtures before self-heating, self-ignition and explosive effects.

Data based on the differential thermal analysis gives more information about fire risk assessment that Manual Test recommended by IMDG Code.

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Chapter 15. Human factors and crew resource management

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15.1
Problem behaviours among children of Filipino seafarers in Iloilo City, Philippines

V.B. Jaleco, M.G. Gayo, Jr., R.L. Pador & R.A. Alimen
John B. Lacson Foundation Maritime University-Molo, Iloilo City, Philippines

ABSTRACT: The purpose of this study was to ascertain the problem behaviours among children of Filipino seafarers in Iloilo City, Philippines. The researchers used random sampling technique to determine the 200 respondents of the study. This research employed the descriptive method of analysis. The statistical tools were frequency and rank to describe the children problem behaviours. When taken as an entire group, data showed that the problem behaviours were self-centeredness, substance use, delinquency, and physical aggression. When grouped according to program, the problem behaviours were self-centeredness, delinquency, physical aggression, and substance use as reference to high school program, while those who were in college, the problem behaviours were self-centeredness, substance use, delinquency, physical aggression. When grouped according to sibling rank, the results showed that out of the 76 eldest children, the problem behaviours were self-centeredness, substance use, delinquency, and physical aggression. While, the problem behaviours of the 66 middle children of Filipino seafarers were self-centeredness, substance use, physical aggression, and delinquency. The 58 youngest children of Filipino seafarers' problem behaviours were self-centeredness, substance use, physical aggression, and delinquency. When grouped according to gender, male children problem behaviours were self-centeredness, delinquency, substance use, and physical aggression. And, 86 female children problem behaviours were self-centeredness, delinquency, substance use, and physical aggression. As to the marital status, children whose parents were living, the problem behaviour were self-centeredness, substance use, delinquency, and physical aggression. Children of Filipino seafarers who had separated parents, the problem behaviours were self-centeredness, substance use, physical aggression, and delinquency

1 BACKGROUND AND THEORETICAL FRAMEWORK OF THE STUDY

On the occasion of the World Day of Immigrants and Refugees in 1993, celebrated as the International Year of the family, Pope John Paul II sounded out this appeal: "I would like to ask all those who at all levels are concerned with promoting the authentic well-being of the family, to consider carefully the problems of the immigrants, precisely in the light of the particular difficulties which they face today." Also, Castro (1993) mentioned that difficulties in married life can be a source why some couples experience problems in life and may put their lives in danger, as well as the plight of the families of migrant workers; the families of those obliged to be away for long periods, such as sailors and all kinds of itinerant people. In these cases, the effect of prolonged separation is that the wife, left behind with the children, has to assume unaccustomed roles, like becoming the head of the household. Here, several problems may arise especially in the children who grew up without the presence of their fathers.

The children of Filipino seafarers should therefore be responsible and well motivated towards their studies for their parents work abroad for the sake of their future.

According to Xin, Zhou, Bray and Kehle (2003), behavioural dysfunction in children and adolescents has been an important field in research. In the studies conducted by Donovan and Jessor (1985), they have found that problem behaviours, such as substance, aggression, delinquency, and even early sexuality, are positively correlated with their academic performance.

Furthermore, Jessor, Donovan, and Costa (1991) theorize a framework for understanding the relationship between problem behaviours, that is, the strong positive association between problem behaviours can be attributed to a single common factor, namely, unconventionality.

Moreover, the work of Achenbach and his colleagues (1991), has been noted to have an important contribution to the research on problem behaviour. Their work has led to the distinction between internalizing problem behaviours (i.e. withdrawn, somatic complaints, anxiety and depression) and externalizing problem behaviours (i.e. defiance, impulsivity, disruptiveness, aggression, antisocial features and over-activity).

The rationale of this study thus, was to ascertain the common problem behaviours among children of seafarers.

The conceptual framework of the study is summarized in Figure 1.

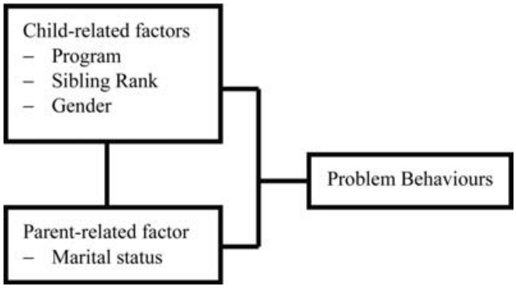

Figure 1. Conceptual framework of the study.

2 STATEMENT OF THE PROBLEM

This study was to ascertain the problem behaviours among children of Filipino seafarers in Iloilo City, Philippines.

Specifically, this study sought to answer the following questions:

1 What are the problem behaviours among children of Filipino seafarers in Iloilo City, Philippines when taken as an entire group?
2 What are the problem behaviours among children of Filipino seafarers in Iloilo City, Philippines when grouped according to (a) gender, (b) program, and (c) sibling rank?
3 What are the problem behaviours among children of Filipino Seafarers in Iloilo City, Philippines when parents are grouped according to marital status?

3 METHOD

The researchers employed the descriptive method in this study based on Travers (in Sevilla, 2002; Jesser, 1985) and Best and Khan (1998). The method employed was to describe problem behaviours among children of seafarers in relation to their academic performance.

4 RESPONDENTS

The distribution of children of seafarers according to certain categories is presented in Table 1.

5 DATA-GATHERING INSTRUMENTS AND PROCEDURES

The investigators distributed the validated instruments to gather data on child and parent related-factors, and problem behaviours among children of seafarers in Iloilo City. To determine the problem behaviours, the investigators used the instrument entitled "Problem Behaviours Evaluation Questionnaire" adapted from Donnovan and Jessor (1991) entitled "Problem Behaviours Evaluation Rating Scale." The research instruments were personally administered by the researchers to the children of Filipino seafarers in Iloilo City, Philippines. The data gathered for this study were tabulated, analysed and interpreted using appropriate statistical tools.

Table 1. Profile of Respondents.

Category	f	%
Entire group	200	100
Child-related factors		
A. Program		
College	100	50
High school	100	50
B. Sibling rank		
Eldest	76	38
Middle	66	33
Youngest	58	29
C. Gender		
Male	114	57
Female	86	43
D. Parent's Marital Status		
Living Together	140	70
Separated	60	30

Table 2. Problem behaviours or respondents as an entire group.

Problem behaviour	f	%	Rank
Self-centered behaviour	174	87.0	1
Substance use	15	7.5	2
Delinquent behaviour	8	4.0	3
Physical aggression	3	1.5	4

6 RESULTS

When taken as an entire group, Table 2 shows that of the 200 children of Filipino seafarers the problem behaviours were self-centered behaviour (f = 174, 87%), substance use (f = 15, 7.5%), delinquent behaviour (f = 8, 4.0%), and the least was physical aggression (f = 3, 1.5%).

The data are summarised in Table 2.

When grouped according to program, Table 3 reveals that out of 100 high school children of Filipino seafarers, the problem behaviours were self-centered behaviour (f = 92, 92%), delinquent behaviour (f = 4, 4%), physical aggression (f = 3, 3%), and the least was substance use (f = 2, 2%). While, 100 college level children of Filipino seafarers revealed that their problem behaviours were self-centered behaviour (f = 86, 86%), substance use (f = 6, 6%), delinquent behaviour (f = 5, 5%), and the least was physical aggression (f = 3, 3%).

The data are summarized in Table 3.

When grouped according to sibling rank, Table 4 shows that out of 76 eldest children of Filipino

Table 3. Problem Behaviours among Children of Seafarers when Grouped According to Program.

Category	Problem behaviour	f	%	Rank
High school				
	Self-centered behaviour	92	92	1
	Delinquent behaviour	4	4	2
	Physical aggression	3	3	3
	Substance use	2	2	4
College				
	Self-centered behaviour	86	86	1
	Substance use	6	6	2
	Delinquent behaviour	5	5	3
	Physical aggression	3	3	4

Table 4. Problem Behaviours among Children of Seafarers when grouped according to Sibling Rank.

Category	Problem behaviour	f	%	Rank
Eldest				
	Self-centered behaviour	27	35.54	1
	Substance use	26	34.21	2
	Delinquent behaviour	17	22.37	3
	Physical aggression	6	7.89	4
Middle				
	Self-centered behaviour	28	42.42	1
	Substance use	16	24.24	2
	Physical aggression	12	18.19	3
	Delinquent behaviour	10	15.15	4
Youngest				
	Self-centered behaviour	27	46.75	1
	Substance use	23	39.66	2
	Physical aggression	6	10.34	3
	Delinquent behaviour	2	3.45	4

seafarers the problem behaviours were self-centered behaviour (f = 27, 35.54%), substance use (f = 26, 34.21%), delinquent behaviour (f = 17, 22.37%), and the least was physical aggression (f = 6, 7.89%). While, the 66 middle children of Filipino seafarers, the problem behaviours were self-centered behaviour (f = 28, 42.42%), substance use (f = 16, 24.24%), physical aggression (f = 12, 18.19%), the least was delinquent behaviour (f = 10, 15.15%). And 58 youngest children of Filipino seafarers the problem behaviours were self-centered behaviour (f = 27, 46.75%), substance use (f = 23, 23%), physical aggression (f = 6, 10.34%), and the least was delinquent behaviour (f = 2, 3.45%).

The data are summarized in Table 4 .

When grouped according to gender, Table 5 shows that of the 114 male children of Filipino seafarers the problem behaviours were self-centered behaviour (f = 50, 43.86%), delinquent behaviour (f = 36, 31.58%), substance use (f = 18, 15.79%), and the least was physical aggression (f = 10, 8.77%). And, 86 female children of Filipino seafarers the problem behaviours were self-centered behaviour (f = 37, 43.02%), delinquent behaviour (f = 21, 24.42%), substance use (f = 16, 18.61%), and the least was physical aggression (f = 12, 13.95%).

Table 5. Problem Behaviours among Children of Seafarers when Grouped According to Gender.

Category	Problem behaviour	f	%	Rank
Male				
	Self-centered behaviour	50	43.86	1
	Delinquent behaviour	36	31.58	2
	Substance use	18	15.79	3
	Physical aggression	10	8.77	4
Female				
	Self-centered behaviour	37	43.02	1
	Delinquent behaviour	21	24.42	2
	Substance use	16	18.61	3
	Physical aggression	12	13.95	4

Table 6. Problem Behaviours among Children of Seafarers when grouped according to Parents' Marital Status.

Category	Problem behaviour	f	%	Rank
Living together				
	Self-centered behaviour	57	40.72	1
	Substance use	36	25.72	2
	Delinquent behaviour	27	19.28	3
	Physical aggression	20	14.28	4
Separated				
	Self-centered behaviour	21	35.00	1
	Substance use	18	30.00	2
	Physical aggression	16	26.67	3
	Delinquent behaviour	5	8.33	4

The data are summarized in Table 5.

When grouped according to parents' marital status, Table 6 shows that of the 140 children of Filipino seafarers whose parents are living together, the problem behaviours were self-centered behaviour (f = 57, 40.72%), substance use (f = 36, 25.72%), delinquent behaviour (f = 27, 19.28%), and the least was physical aggression (f = 20, 14.28%). While the 60 children of Filipino seafarers whose parents are separated the problem behaviours were self-centered behaviour (f = 21, 35.00%), substance use (f = 18, 30%), physical aggression (f = 16, 26.67%), and the least was delinquent behaviour (f = 5, 8.33%).

The data are summarised in Table 6.

7 CONCLUSIONS

In view of the findings, the following conclusions were drawn:

Generally, the problem behaviours exhibited by children of seafarers were self-centered behaviour, substance use, delinquent behaviour, and the least was physical aggression. It is also noteworthy that respondents who are youngest have a higher percentage in physical aggression, as well as the high school group, and those whose parents are separated.

8 RECOMMENDATIONS

Based on the findings and conclusions of this study, the researchers arrived at the following recommendations:

1. To address the problems of the children of Filipino seafarers, seminars, trainings, and personality development including psychological aspects should be given more attention by the personnel of the guidance office.
2. Family life and marriages shall be included in the psychology subjects of the students in college level this could be done by Instructor's Guide (IG) revision.
3. Counselling program shall be conducted among children of Filipino seafarers especially those who pose greater behavioural problems.
4. Further studies should be conducted to ascertain the problem behaviours among children of seafarers.

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15.2 Predicting emotional intelligence in maritime management: Imperative, yet elusive

E.S. Potoker & J.-A. Corwin
Maine Maritime Academy, Castine, Maine, USA

ABSTRACT: There is extensive literature addressing the subject of "emotional intelligence" (EI) and its importance to the profile of leaders and models of leadership. Despite what some have argued as the sine qua non of leadership, there are arguably few, if any, valid instruments available to predict demonstration of EI competencies. This paper focuses on EI and challenges to measurement as it relates to leadership development in maritime management – where EI competencies are deemed critical to effective performance. The authors review and evaluate current instruments that claim to measure EI, survey hiring practices in selected companies in the shipping industry, and make recommendations for further research.

1 INTRODUCTION

There is extensive literature addressing the subject of "emotional intelligence" (EI) and its importance to the profile of leaders and models of leadership. Yet, despite what some claim to be the "sine qua non" of leadership (Goleman 1998, p. 93), there are arguably few, if any, valid instruments available to predict demonstration of EI competencies in the workplace. This paper focuses on EI and challenges to measurement as they relates to leadership development in maritime management – where EI competencies are generally acknowledged as critical to effective job performance. The paper proceeds as follows:

1 definition of EI;
2 review and evaluation of current instruments that claim to measure EI;
3 rationale for study;
4 survey results of hiring practices in selected companies in the shipping industry; implications to the imperative for testing and measurement of EI;
5 and, recommendations for further research.

2 DEFINING EMOTIONAL INTELLIGENCE

The term emotional intelligence, while popular in many academic and practitioner forums, continues to generate significant controversy regarding its meaning, its measurement, and its predictability or validity (Livingston & Day 2005, p. 757). Although definitional grounding is important to this paper, a comprehensive review of the literature devoted to defining EI lies beyond the scope of this study. Suffice to say that we – the authors – frame the understanding of EI, in part, around the five competencies and personality attributes posited by Daniel Goleman (1998, p. 95):

– self-awareness: The ability to recognize and understand one's moods, emotions, and drives as well as their effect on others.
  Demonstrated: self-confidence; realistic self-assessment; self-deprecating sense of humor;
– self-regulation: The ability to control or redirect disruptive impulses and moods; the propensity to suspend judgment – to think before acting.
  Demonstrated: trustworthiness and integrity; comfort with ambiguity; openness to change;
– motivation: A passion to work for reasons that go beyond money and status; a propensity to pursue goals with energy and persistence.
  Demonstrated: strong drive to achieve optimism, even in the face of failure; organizational commitment
– empathy: The ability to understand the emotional makeup of other people; skill in treating people according to their emotional reactions.
  Demonstrated: expertise in building and retaining talent; cross-cultural sensitivity; service to clients and customers
– Proficiency in managing relationships and building networks; an ability to find common ground and build rapport
  Demonstrated: effectiveness in leading change; persuasiveness; expertise in building and leading teams.

Reuven Bar-On's definition (1997) is another that informs this paper as he addresses, "…noncognitive capabilities, competencies, and skills that influence one's ability to succeed in with environmental demands and pressures" (p. 14). Non-cognitive refers to the "emotional, personal, and social components of intelligent behavior" (Bar-On 1998, p. vii). These capabilities appear to be particularly important given the environmental variables inherent in maritime management, and so are included as a consideration.

3 MEASURING AND PREDICTING EI

Consensus is also clearly lacking regarding availability of instruments that accurately predict demonstration of EI competencies. Three tests that are currently used with arguable claims of some success are The Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT–MHS Multi-Health Systems), the BarOn EQ-i (Bar-On 1997) and the Emotional Competence Inventory – e.g., ECI360 (Hay Group 1999-2005). Because each test defines emotional intelligence differently – e.g. focusing in part or not on personality traits, cognitive abilities, and/or other arrays – users might not necessarily have just the one test to meet their needs. Additionally, making comparisons of different test results is not feasible as comparability is simply not possible: Some tests results are based on self-reporting models (e.g., the BarOn EQ-i); others incorporate observer input and self-reporting (e.g., the ECI360), and so on.

Another concern, as with any instrument, involves that of reliability and validity. Reliability – does the instrument consistently measure over time what it purports to measure? Construct validity – is there evidence that the instrument measures what it claims to measure? Construct validity claims are frequently supported through triangulation, where multiple instruments/observers corroborate findings. This is problematic, however, in the case of EI instruments for reasons discussed earlier. Predictive validity, or the degree to which the test is accurate in forecasting on-the-job performance, is particularly important to this paper. Nevertheless, it is one thing to hypothetically score high (or low) in a test setting for EI – particularly if by self-reporting methods (versus impartial observers). It is quite another when one factors in the work environment such as weather, fear, terrorism, and a multitude of other variables such as crew diversity – all of which have the potential to affect operationalization of predicted performance. Crew diversity is a factor of life on ocean going vessels, many of which bear foreign flags and count on crews representing many nations, both developed and developing. Therefore, if we add cross-cultural and national dimensions to measuring and predicting EI as defined earlier, the challenges loom even larger. Alternatively stated, history has proven that results obtained in an "antiseptic" or closed system will not necessarily translate in real world situations where the environment intervenes regularly.

An Internet search of the importance of EI to decision making reveals over 26,000 cites illustrating its value across industries. Therefore, if it were available, predictive validity for EI would not be uniquely important to maritime management. Yet, the rationale to meet these needs in this particular industry appears particularly impelling in a global post 9/11 environment, which brings us to the section that follows.

4 RATIONALE FOR STUDY: A MARITIME PERSPECTIVE

> *. . . the prospect of a relationship between EI, leadership and individual, group and organizational outcomes is sufficiently compelling to attract the attention of researchers who will resolve the question and move leadership theory and understanding of social influence to its next stage (Brown and Moshavi 2005, p. 870).*

In March of 2006, Pamela Turner, Assistant Secretary for Legislative and Governmental Affairs of the U.S. Department of Homeland Security, directed a letter to Congress regarding the results of a project that implemented the Crew Endurance Management System (CEMS) on towing vessels. Crew endurance is "the ability to maintain performance within safety limits while enduring job-related physical, psychological and environmental challenges" (Crew Endurance Management 2006). Management of the elements that heighten risk that leads to poor performance and/or human failures is a goal of CEMS. The report also included a description of the resources that would be needed to implement the CEMS on all U.S. flag-towing vessels (CEMS Demonstration Project Report, 2006). While the report's main concern is to reduce marine casualties as a result of stress and fatigue, the opening statements of the report point to the imperative not only to find predictive indicators for EI, but also for the maintenance and development of EI competencies:

> *Numerous studies indicate that human factors contribute to the vast majority of marine casualties. Most of these human factors relate to cognitive abilities such as situational awareness and situational assessment (p. 1).*

This imperative prompted the authors of this paper to determine if and how EI competencies were currently being assessed in the shipping industry. Discussion of that survey and its components are addressed in the section to follow.

5 METHODOLOGY

Through the Careers/Cooperative Education Office of Maine Maritime Academy in Castine, ME., we identified 100 individuals in management positions in a wide range of maritime-related companies. These included, but were not limited to major U.S. shipping, offshore drilling, tug boat service, marina management, and logistics and related transportation companies, and pilots' associations. A survey, including Goleman's definition (1998), was mailed to all with the request that they rank order the importance of EI competencies. They further were asked to note whether their company or if they themselves screened for these competencies through recruitment, hiring, selection and/or their performance appraisal process. Appendix A of complete paper includes survey details.

6 FINDINGS AND DISCUSSION

Thirty individuals surveyed responded over a four month period–from July to October of 2006. Eight of those who did not respond were due to mail returns because of outdated addresses or personnel changes. We feel that this response rate is a respectable one given the nature of the industry–particularly as many of these individuals frequently ship out for months at a time–making surveying a challenge at best. Results are as follows:

Category 1. *Please read the definition of EI competencies. Do you feel that these competencies are important to effective management in the shipping industry?*

100% of the respondents voted affirmatively ("Yes"). Several added comments that are illustrative of the importance of EI:

Regarding their relative importance specific to the maritime industry:

– "Especially onboard the vessel when they are together 24/7."
– "Within the boundaries of the command structure aboard a ship."
– "Due to the close quarters and strenuous work conditions our crewmembers experience, it is imperative we take each competency into account when crewing and managing our vessels."

One individual found these competencies to be uncommon in a shipboard environment and added:

– "These sophisticated 'touchy/feely' concepts are difficult to teach or impart to those who manage others. . . ."
– "As a C/M[Chief Mate], a department head, directing/leading/working w/others has many different requirements that vary from managing another officer, with skills and a permanent job aboard, unlicensed crew, skilled/semi-skilled with a permanent job aboard, to unlicensed, semi-skilled without permanent job status/one trippers, all require somewhat different approaches."

Regarding their relative importance in any industry:

– "The EI competencies appear important to lead a productive & fulfilling life."
– "It's difficult to quantify which are most important, but they are all ingredients for most effective management."
– "In any industry, for that matter." (2 responses)
– "Absolutely. I feel these concepts are key to nearly anything one attempts in life."

Category 2. *In order of importance from 1–6, with 1 being the most important, pls. rank order the EI competencies that you consider to be important to effective management in the shipping industry.*

It was obvious that respondents had difficulty rank ordering the six EI components listed in Appendix A. In fact, three individual comments suggested that it was difficult to pull them apart in importance. One individual rated all 6 as #1; others rated several equally, making it very challenging to attempt to represent the data in Figure form. For those who provided comments, it could be argued that they viewed the competencies from their specific job responsibility or personal vantage point – understandably. As example, a "marine personnel administrator" favored "e" as #1 in importance, commenting that vessel masters who promote teamwork appeared more effective in her view than others. An "owner" of a U.S. based, but Mid-East affiliated maritime company emphasized the importance of "d" which includes "cross-cultural sensitivity." He states, "Any chump can turn a wrench or steer a course. Only a human relations 'expert' can motivate a team." A "personnel administrator" commented that all were important when deciding if an individual would receive a permanent job aboard a ship or a promotion to a position of higher responsibility.

Despite the challenge of representing the data from Category 2 in figure form due to double-counting of several items, it is displayed in the form of a scatter gram in Figure 1. As explanation, if "b" was considered #1 in importance and "c" was also considered #1 in importance by the same individual, those choices are both represented on the scattergram.

For Category 2 only, four individuals are not represented due to the fact that they obviously did not either follow or understand the instructions.

The most interesting findings (to the authors of this paper) were the highs and lows. Choice "b" or "self-regulation" clearly rated #1, with "e", "proficiency in managing relationships" clearly in second place. "Self-awareness" was top choice in the #2 ranking. A total surprise to the authors was the fact that "f" was ranked overwhelmingly least in importance. However, that may be explained by a qualitative comment that was offered by one respondent who stated, " 'f' is too

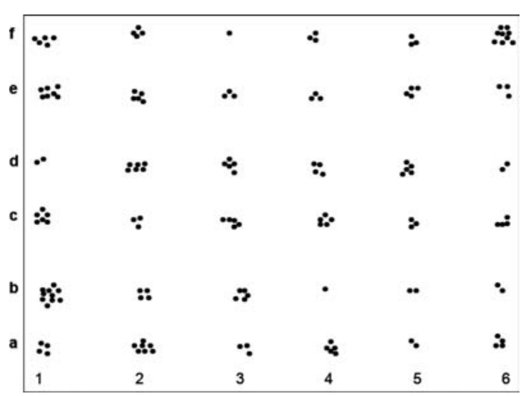

Figure 1. Category 2 – Rank Ordering of EI Competencies.

general a definition." Perhaps there was a need for further explanation that might have influenced the results. While the data results are interesting, the authors are unwilling to jump to generalizations without further research, discussed later in the paper.

Category 3. *To the best of your knowledge, does your Company or do you screen for these EI competencies in recruitment, hiring, selection, and/or in the performance appraisal process?*

- Twenty-two or seventy-three percent: "Yes" – many with qualifiers, to be discussed.
- 2 individuals: did not know, but did offer opinions.
- Six: "No."

Regarding the "yes" choices, comments clearly indicated that many of the components of EI are taken into consideration for after-hire decisions: e.g., for retention, promotions to management or senior officer positions such as Captain or Chief Engineer as part of the performance appraisal process, and in decisions for granting part-time hires permanent job status. Several comments illustrated that a formal process for measuring these competencies is not in place. Representative examples of such qualifying comments are as follows:

- "Informally – we do not use a formal tool."
- "Not done in a formal way yet; is part of evaluation and discussions by people making selections."
- "Partly, difficult to evaluate empathy and self-awareness in an employment candidate. [italicized by authors of paper].
- "More so in the performance appraisal process; most hiring is done based on professional qualifications & experience."
- "Theoretically yes; in practicality, somewhat to not at all; it often is based on seniority more than these qualifications or dogged determination."
- "We try, but it's difficult in an interview to see how people really are."

[One respondent, who checked "no," indicated that "but the factors become evident very quickly."]

Only one individual claimed to screen for these competencies when interviewing potential candidates. Three others, *while attesting to the importance of EI competencies on Question 1*, pointed to the influence of unions in hiring decisions. First-level decisions for hire of unlicensed positions often related to basic performance issues such as showing up to work on time and getting work done in a timely matter. As indicated earlier, for promotions, these three also indicated that many of the EI components would be taken into consideration, although they did not offer how. One individual makes this illustrative statement regarding the role and influence of unions in the hiring process which, in turn, indicates why EI components are generally considerations "after the fact" (i.e., the hire) decisions:

- "Personnel are only screened for these competencies with regards to retention. Initial hires are appointed to employment with a company by a union, and the unions recognize their role as being one of protection for all members, versus the culling or development of individuals."

7 CONCLUSIONS AND RECOMMENDATIONS

While EI competencies were deemed important by all who were surveyed, and considerations in the performance appraisal (PA) process for varying reasons such as retention and rehire for permanent positions and promotions, it was unclear as to how these competencies were evaluated. In part, this is a limitation to the survey itself as that question was not specifically asked. Nevertheless, with EI only as an informal consideration for many in the performance appraisal process, and a minimal to non-consideration in hiring due to union/and or other variables involving full or part-time hiring, one might question how the road to leadership could be optimized if predictive indicators for EI in this industry could be identified. Additionally, how might training and career development be optimized if build around an EI model? Another concern relating to the informality of the EI screening process involves the possibility of rater bias and legal repercussions that might ensue due to perceptions of "informality" (aka, "unfairness") in promotion and retention decisions.

Research results point to numerous and worthwhile areas for further research, including, but not limited to:

1. surveying further how EI is presently being assessed in this industry;
2. developing a formal, performance-based Performance Appraisal model/instrument that is grounded in EI competencies for purposes of training – teaching of specific EI-related skills, development – career improvement and organizational effectiveness;
3. continued effort to identify tests for predictive validity of EI;
4. studies using personnel samples to assess the relationship between EI components and promotions within the maritime industry; and,
5. assessment to discern if the importance and the respective value of each of the EI competencies (Goleman, 1998) is shared across cultures. This last area of research is still an un-chartered one for EI in general, and appears important given the diversity of crews and foreign-flagged vessel ownership that is characteristic of this industry.

In short, we are still a long way from identifying and measuring a quality (EI) that appears crucial to any industry. Nevertheless, in a post 9/11 world where teamwork, cross-cultural sensitivity, and self-regulation and awareness (and more) in uncertain surroundings are of paramount importance, continued research in this area appears as imperative as ever. We invite interested faculty and others to contact us if there is interest in collaborating regarding further cross-cultural survey research that needs to be done on this issue.

elaine.potoker@mma.edu

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15.3 Officers' shortage: Viewpoints from stakeholders

G. Eler, J. Calambuhay, L. Bernas & M. Magramo
John B. Lacson Foundation Maritime University, Iloilo City, Philippines

ABSTRACT: This qualitative research looked into the views and opinions of the different stakeholders in the shipping/manning on the shortage of qualified and competent officers to handle modern ships of today. This shortage poses the biggest challenge shipping companies are currently facing. An in-depth interview of the participants was utilized in the data gathering for this study. It also looked into what maritime schools can do to help solve this problem. Findings showed that there are many sectors involved and have contributed to the present shortage of officers, namely: the shipping companies, the manning companies, the maritime schools, government agencies and the attitude of the seafarers themselves, not to mention the continuing demand for new vessels brought about by globalization of trade and industry.

1 INTRODUCTION

Ninety percent (90%) of the world trade is carried by the international shipping industry. Without shipping the import and export of goods necessary for the modern world would not be possible (Shipping and world trade, 2007). Seaborne continues to expand, bringing benefits for consumers across the world through low and decreasing freight costs. The growing efficiency of shipping as a mode of transport and increased economic liberalization, and the prospects for the industry's further growth continue to be strong. There are around 50,000 merchant ships trading internationally and transporting almost every kind of cargo.

The worldwide population of seafarers serving on internationally trading merchant ships is estimated to be in the order of 466,000 officers and 721,000 ratings.

The OECD countries (North America, Western Europe, Japan, etc.) remain an important source for officers, but growing numbers of officers are now recruited from developing countries, especially the Far East and South East Asia.

The Philippines and India are very significant maritime labor supply nations, with many seafarers from these countries enjoying employment opportunities on foreign flag ships operated by international shipping companies. China has also seen a large number of seafarers, but at the moment most of them work on the Chinese fleet, meeting domestic requirements.

Demand for skilled workers is escalating brought about by new ships built and delivered since 2004 and more ships scheduled to be delivered even beyond 2012 according to Suri, (2007). He further stressed that the world economy is forecast to continue its bull run into the next decade, pulling the world tonnage into new highs. Accordingly, major crew supplying countries are unable to cope with increased demand for officers.

As of 2006, the current shortage corresponds to 4 percent of the total workforce (16,000 officers) and predicts a 12 percent shortfall (46,000) by 2010 according to a study conducted by Belcher, et al. (2003).

With the current growth in new ships being built and scheduled for delivery until 2012, the shortage is estimated to be 67,800 officers (Odd Magne Skei, 2007).

With this demand for officers in the next 5 to 10 years, the Filipino seafarers will continue to be in great demand in the world manning industry.

It is in this context that this study was conducted.

2 THE PROBLEM

This study aimed to determine the following:

1. The factors that led to the shortage of officers;
2. The role of the shipping and manning companies in solving this problem;
3. The intervention that the maritime schools could initiate to help alleviate the shortage;
4. The role of the Philippine government agencies in solving the shortage.

3 METHOD

This research employed the interview and focused group discussions in data-gathering. The participants of this study were the different manning company managers and the seafarers. It utilized an in-depth interview of the participants.

The participants of the study were the different ship owners and presidents of various shipping companies. The interviews took place on the basis of informed consent. Focused group discussion took place at the respective offices of the ship managers. All the interviews and focused group discussion were vide-taped recorded and transcribed verbatim.

3.1 *Modes of analyses*

There are a lot of factors that led to the shortage of officers, based on the interview conducted among the key informants. The following are noted:

3.1.1 *The role of the shipping companies and ship owners*

The shipping companies themselves or the ship owners were reluctant or hesitant in promoting Filipino junior officers to senior officers because the ship owners are afraid this would displace their own officers. This was stressed by Mr. Vicente Aldanese (2007). This was also affirmed by Mrs. Carla S. Limcaoco (Philippine Transmarine Carriers) who said: "These are glass of ceiling and glass walls during those time; Filipinos can only assume positions in bulk carriers, general cargoes and tankers. According to Mrs. Virginia Linesis (K-Line Maritime Training Center, President) the same situation is happening on Japanese vessels because it is only now that Filipino senior officers are given the opportunity to take a command or given the responsibility of master or captain on board. In the past, Filipinos were not given the opportunity to be in command of Japanese vessels. The same observation was mentioned by Mrs. Brenda Panganiban (Bouvet Shipping Management Corporation); who said: "the company is having difficulty in hiring the top 4 or senior officers (management level). Based on statistics, the manning industry is really experiencing shortage of qualified and competent officers because the industry was not able to foresee that this would happen." According to Capt. Martinez, the foreign principals or owners had greatly contributed to this problem because "they were not willing to give chances to those who are capable of being promoted for the position."

3.1.2 *New ships being built*

Statistics show that from 2006 new vessels into the global fleet of 5,650 within 2010 will require an estimated 67,800 officers including 22,600 senior officers (Skei, 2007). This further aggravates the shortage of officers in the world manning industry. According to Mrs. Carla S. Limcaoco, the people who ordered ships are the board of directors, owners of the shipping companies have not seen this problem on shortage coming because they have not invested in people. The owners presumed that there will always be people who will be available to handle or man their ships.

A ship takes six months to build, but it takes four years to produce a junior officer and then six years more for him to attain senior ranks. While ship production has shot through the roof, officer production has been totally neglected.

3.1.3 *Training infrastructure in the Asia-Pacific has not been developed for increased production of officers*

This was stressed by Suri (2007) during the 8th Asia-Pacific Manning Conference in Manila last November 14–15, 2007. The production of officers in the Philippines-the largest supplying country – dropped from above 12,000 annually to below 5,000 after the crackdown on sub-standard training institutes.

Likewise, production in India has not seen any increase in many years, although India has tremendous potential to do so. Other crew supplying countries in the Indian sub-continent- Bangladesh, Pakistan and Sri Lanka lacks the political recognition of maritime training as an important national issue or the inabilities of the academies to attract potential sponsors and investors, continue to restrict growth. According to Mr. Ajoy Chaterbee (Kumar, 2007) "the shortfall of seafarers negatively impacts the shipping industry as a whole whereas both the on-board and on- shore maritime related work posts face manning problems that may directly threaten the existence of the shipping activity and the sustenance of maritime know-how".

Production in China has seen some growth, but the growth is dwarfed by the growth in Chinese domestic fleet, giving no relief to the international demand. In any case, much more needs to be done to improve the standards of training as well as English language proficiency. Apart from this reality, China is short of 13,000 high-level maritime workers as the shipping industry continues to develop according to Xen Dingding(2006). Today, China ranks 9th in the top 20 largest shipping flags (Shipping and World Trade, January 2007) and ranks 6th among the top contracting countries by number of vessels on order.

3.1.4 *The attitudes towards the seafaring profession*

The induction of new entrants into the seafaring profession has not increased in proportion to the attrition of experienced seafarers. Many alternate career options that are lucrative, comfortable and socially recognized have pushed seafaring down as a career choice. The best of the youth today look for honorable careers with social status, perks, five- day/week work, clear path and equal or higher wage/benefits package than seafaring can offer. The incentives that the industry offers to the officers are limited to the matching what other professions offer and lack a comprehensive packaging as an industry standard. Seafaring is not the preferred profession for youngsters in developed nations according to Grover (in Kumar, 2007).

3.1.5 *The competencies of the new graduates from maritime schools are always questioned*

This idea was disclosed by Mrs. Virginia Linesis, President of K-Line, one of the respondents of the study. Along with it is the issue of the competence of the teachers. These teachers are not recently disembarked from the vessel, meaning they have been teaching long enough and have not undergone upgrading on board vessels. The school, according to one of the interviewee: "The school should also look into its curriculum; look at the issue of its relevance in today's world. There are certain subjects that are non-negotiable that students have to study. But are they relevant?"

3.1.6 *There are government agencies that hamper the growth of our officers, like the PRC Reg. Act 3544*

After passing the board examinations, they are supposed to be given certificate of competency (COC), however they have to attend various upgrading courses like the management level course (MLC) required by the agency which further delays the issuance of said certificates.

4 FINDINGS

1. The shipping companies themselves or the ship owners were reluctant or hesitant in promoting Filipino junior officers to senior officers because the ship owners are afraid this would displace their own officers. The foreign principals or owners had greatly contributed to this problem because "they were not willing to give chances to those who are capable of being promoted for the position."
2. Construction of new ships brought about by the growth in the world economy further aggravates the problem of shortage of officers in the world manning industry. Statistics show that from 2006 to 2010, new vessels into the global fleet of 5,650 will require an estimated 67,800 officers including 22,600 senior officers (Skei, 2007).
3. Training infrastructure in the Asia-Pacific has not been developed for increased production of officers. The production of officers in the Philippines – the largest supplying country – dropped from above 12,000 annually to below 5,000 after the crackdown on sub-standard training institutions.
4. The induction of new entrants into theseafaring profession has not increased in proportion to the attrition of experienced seafarers. Seafaring is not the preferred profession for youngsters in developed nations.
5. The maritime schools should review its curriculum as to its relevance in today's industry demands.
6. The additional requirements of the Professional Regulations Commission contribute to the delay in the acquisition of the certificates of competency among the officers passing the board exams.

5 RECOMMENDATIONS

1. The need to improve the image of the maritime career and to attract young people to the seafaring profession is of utmost importance today in order to sustain the growth in international shipping activities. Human resource development is more complex and time consuming than development of trade and technology. Human resource, unlike machineries, cannot be drafted on drawing boards, nor programmed on computers. A ship takes 6 months to build, but it takes 4 years to produce a junior officer, 6 years more for him to attain a senior rank.
2. There is a need to promote officers who are already holding higher licenses and qualified to assume the next higher position especially Chief Mates and 2nd Engineers.
3. The career path of officers and crew should be mapped out in order to promote loyalty to the company. This has been practiced by some Japanese companies like the K-Line whose retention rate of its officers is 96%.
4. The shipping companies should invest in people. As much as possible, they need to establish tie-ups or linkages with maritime schools who are the producers of competent graduates. Scholarship grants to deserving students should be enhanced.
5. Improve the quality of deck and engine graduates of the maritime schools. While most Filipinos are able to speak English, there is still a need to improve the speaking competencies of the graduates of the maritime schools. There is also a need to focus attention in mathematics, science and physics.
6. The Professional Regulation Commission (PRC) should implement the walk-in examination (WES) system as soon as possible.

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15.4
A noble profession called seafaring: The making of an officer

M. Magramo & L. Gellada
John B. Lacson Foundation Maritime University, Iloilo City, Philippines

ABSTRACT: This study aimed to determine the perceptions of the managers in the shipping and manning companies in the Philippines and the seafarers regarding the nobility of the seafaring profession in the light of the shortage of competent officers. It utilized the interview approach in gathering data. It was found out that in other countries especially in OECD or highly industrialized countries, the youth today are no longer interested in the seafaring profession. Working on board ships is becoming less attractive for students coming out of the schools and colleges. In the past, seafarers were paid better than their peers on shore, and they had the opportunity to travel across the world. In the Philippines, it is still preferred by some students whose fathers or relatives are seafarers. They have seen that the profession is financially rewarding and it is perhaps the best, if not the only way to improve their quality of life. This study also looked into the perceptions and opinions of the practitioners, the master mariners themselves who once also struggled in order to realize their dreams and aspirations in life. Most of the officers interviewed believed that it takes determination and focus in the job in order to be successful. Thus, students aspiring to become officers and ultimately captains or master mariners must study hard, persevere and be disciplined to be able to overcome any problem along the way.

1 INTRODUCTION

Working on board ships is becoming less attractive for students coming out of the schools and colleges. In the past, seafarers were paid better than their peers on shore, and they had the opportunity to travel across the world. However, both of these have changed. The salary gap between seafarers and those working on shore is minimal. With ports and terminals located away from the city, and ships not staying at the port for a longer period, seafarers do not have an opportunity to explore various countries according to Mr. S. Hajara (http:www.businessline.in/).

Several studies indicate that there is currently a world-wide shortage of officers, corresponding to 4 percent of the total officers (16,000) and the prediction is that by 2012, the shortfall will rise to 46,000(Kumar, 2007).

The shortfall of seafarers has negative impacts on the shipping industry as a whole whereas both the on- board and on- shore maritime related work posts face manning problems that may directly threaten the existence of shipping activity and the sustenance of maritime know- how (Chaterjee, in Kumar, 2007).

Japanese shipping companies plan to hire 10,000 seafarers from the Philippines between 2008 and 2010. (http://www.gma.news.tv/). This was stated by the president of the Philippine-Japan Manning Consultative Council, Mr. /Eduardo Manese. He further said that Japan will increase its merchant fleet of 2,223 as of 2006 to 3,000 by the end of 2010, and further to 4,000 by 2015.

The same opinion was shared by Ambassador Stale Torstein Risa of Norway during the two-day International Maritime Conference hosted by JBLFMU on January 29, 2008. He encouraged maritime schools in the country to give importance to quality-based maritime education and training to meet the demands of the global shipping industry. Risa noted that most of the world's global trade is by sea and that globalization has entirely changed the world's trading patterns with new emerging markets requiring more transport services than ever before. Aside from the expanding off-shore explorations of petroleum resources, the cruise industry also continues to grow. This entails a growing demand for maritime workers. He further stressed: "I believe schools should even seek to follow up and evaluate their graduates' employment experiences. They should keep track of their graduates and to get feedbacks after spending some time at sea and it would be a valuable input in determining if the level of training is adequate, and even offer advice on job satisfaction."

Given the shortage of maritime officers for international vessels, the manning industry is turning to re-packaging what its players say is a "wimpy" image of the Filipino seafaring career according to Stene (in Alzona, 2008). It is on this premise that this study was conducted.

2 THE PROBLEM

This study aimed to determine the actions and measures taken by the different stakeholders in order to entice the youth of today in pursuing a career at sea. The perceptions of the various managers of the shipping and manning companies in the Philippines and other stakeholders, especially the seafarers, regarding the nobility of the seafaring profession in the light of the shortage of seafarers was also looked into.

3 METHOD

This study utilized the descriptive-qualitative method of research. It utilized the phenomenological approach, using an in-depth interview of the key informants. The participants in this study were the managers of the manning companies and the various representatives of the owners of the shipping companies in the Philippines, deck cadets who recently disembarked after completing a one-year training program on board and active seafarers occupying management level positions on board.

3.1 *Modes of analysis*

3.1.1 *Filipinos are excellent seafarers*

The Philippines is number one (1) in the world as far as seafaring is concerned. There is no other industry or profession the country that can boast of being number one. There are some personalities who are number one in the world like Manny Pacquiao or Lea Salonga, but in an industry or profession, no one individual can claim being number one in the world. Thus, in the office, the seafarers wear necktie because they feel that they are real professionals. So there are reasons to promote seafaring profession as a better paying professional job. It is better than most of the professions we know. These were the inspiring words of Mr. Erickson Marquez, president of several manning companies owned by his family and a legacy left to him by his father, the founder of the company. His appeal to the students: "Study! Have an ambition! Don't be satisfied to be able to go on board ships only. Aim to be a captain or chief engineer; your life will not be fulfilled if you don't become one. And you can only do that if you study. And let's get rid of the notion: 'pag mahina, mag-seaman ka na lang; pag magaling ibang profession ("if the intelligence is below average, go for the seafaring profession, if above average go for other professions)."

He added: "So how come we are not doing our best to improve the quality of our students? Without the seafarers our economy would probably suffer more than what we are suffering now. Seafarers are not given attention, despite the fact that this is the profession that the Filipinos will dominate in the years to come."

Let us therefore change or re-direct our mindset, let us treat seafaring as a very old and a noble profession.

3.1.2 *A very old but noble profession*

The statements by Mr. Ericson Marquez are the same words shared by Mrs. Carla S. Limcaoco, Vice-Chairman of the Philippine Transmarine Carriers, Inc. She said: "to enter this career is a special calling. Seafarers should not just do it to see the world free or just earn dollars. They must do it because they believe in the value of the course. They should remember that without ships where would the world economy be? When you find something imported in the supermarket, don't you start to think how it got there? It got there because of ships. How do the cars of Japan go to Europe? How did the gold from China get to the United States? Without ships, the world economy would collapse. So when somebody (sic) decides to be a mariner you become part of a very old but noble profession. It is much more sophisticated now because the level of education required is amazing. I sit here and listen to the competence requirements and berthing requirements; port state control and flag state requirements. And I sit there and tell my senior officer (she is referring to senior deck officers in their company), you cannot imagine how proud I am of you because one day, if you decide to work ashore you can probably sit and do what I am doing. I can never do what you are doing, I have a great respect for what is it they have to (sic) know. And so to me, it's a profession that requires a high level of education and it is a profession that if you conduct yourself properly will give you a very fruitful life.

According to Capt. Jessie Martinez, the president of Global Training Systems Phils., Inc. "Students should do everything, including motivating themselves." He further adds: "They have to give it their best shot. Don't settle for the second best. Try to be the best always. If you will do all these things, this profession becomes easy. In this profession, there is no glorious moment than the first day that you assume the position of the master."

Capt. Rainier Salcedo, 1986 graduate of JBLFMU-Arevalo said that his profession as a seafarer earned him the respect of people both at sea and on land. People in his community appreciated a lot his little contributions that he shared to them.

3.1.3 *A lonely but a challenging job*

Any seafarer will find it difficult to work on board. First of all we are far from our family. The feeling of being away from your family and loved ones is the hardest part according to Capt. Lopez, even harder than the work on board ships. "But life is in itself a sacrifice. So in order for me to provide for my family . . . . I have to work on board but I have no choice because I love my family." Capt. Lopez added: "Being away from my loved ones is the biggest challenge that I have been confronted with. It is a challenge to me as a human being for I have biological needs and must have a biological fulfillment. Thus, when I am in port surrounded by beautiful women, sometimes I can surpass it but at times I cannot."

This was also shared by Capt. Genona who considers that being away from family requires a large amount of patience to work efficiently. "It was difficult but because of training and motivation, I was able to surpass such difficulties". He overcomes homesickness by concentrating in his work.

Capt. Rainier Salcedo, feels the same way. It is not the work on board that he considers difficult but rather, it is the feeling of being away from his family. For him work becomes routine on board the moment that you (sic) have mastered it. He looks at his work as a passion or an art. It is fun working on board because he enjoys it and he doesn't find it boring. He always looks forward that each day is a different day from the previous days. The challenges that he encounters on board makes him a stronger and better person.

Difficulty is a state of mind. Physically it is difficult; mentally it is very difficult, if you are not prepared. But if you are physically and mentally prepared and you know how to sort things out, then everything is easy, and fun according to C/M Arsenal. This is something that a deck cadet must endure and must fully understand in this profession. He must carry on his shoulder a big responsibility when he is on board especially when he becomes an officer. There are instances when he does not get enough sleep in a 24-hour period because of emergencies on board requiring everybody to be alert all the time. He has to deal with the indifference of his senior officers, and if he is not emotionally prepared he will end up crying. But all these are part of being a cadet aspiring to be an officer someday.

3.1.4 *Adjustment with other nationalities*

Most of the key informants interviewed admitted they find it difficult to adjust with other nationalities primarily because of language barrier, not to mention the cultural differences. As a Chief Officer, Capt. Lopez has to adjust to the culture of the Indonesians who are Muslims. He found it difficult at first because, in some instances, Muslim crew members disappeared on the deck in the middle of the work for they must go back to their cabin to pray.

Despite the fact that he was a senior officer on board, Capt. Philip Genona still felt a certain level of discrimination, because Europeans are feeling and thinking superior. But he was not intimidated at all. He simply told them that they were on board to work, that their responsibility, which was to keep the shipboard organization work, and being the officer on board, it was his job to implement company regulations.

For Capt. Rainier Salcedo, he never found it difficult to adjust with Japanese officers even when he was still a deck cadet. Japanese are just like Filipinos or other nationalities; some are arrogant, some are good. Japanese people are polite people. It pays to be courteous and respectful to everybody on board, especially to the officers.

"What the hell is this company in the Philippines It sends me a 51 year old ordinary sailor and a 20 year old third officer. What is this? A joke!" These were the words that C/M Arsenal had to bear when he was first assigned as a Third Officer. So he told the chief officer that it is something that is not within his hands and added: "I will do my job as much as I can and I will prove to you I can do it." Little did he know then, that he was to face the biggest challenge in his career when the captain told him while they were on the bridge: "You know, son I asked from the company to send me a man; they send me a boy. What do you think about this?" C/M Arsenal who was third mate then replied: "Sir, I will prove to you that this boy can do a man's job. And if this boy can do the job better, then shame for the man. And then his captain said: "Yeah, yeah I have a third officer. The boy was able to meet the challenge of his chief officer and captain because he was mentally and emotionally ready even at a very young age."

Capt. Derwin Limpiado never finds it difficult sailing with other nationalities because he can always adjust. "While it is true that European officers think superior over their Asian counterparts, they cannot do otherwise (sic). If you are a Filipino officer and you have Europeans as junior officers or if you are a Master and you have a European Chief officer, there is no problem dealing with them. All that you have to do is prove to them your true worth and that you completely know your job, then there is no problem. Just stand your ground, and later on they will just say sorry. And that is what is good with Europeans, they know how to apologize when they know they are wrong. Sometimes there are Filipinos who will not even admit their mistakes. They will never say sorry.

3.1.5 *What does it take to be a cadet on board?*

"Any ship officer before assuming the position of a third mate must be a deck cadet first. As a deck cadet aspiring to become an officer someday, he must be mentally and spiritually mature. Mentally, because he has to cope up with his studies and physically because he must be prepared for any challenges that would require his physical strength and also the spirituality to always have faith in GOD that HE will never leave him behind and will support him in whatever he does that is right." These were the words of Deck Cadet Lamasan when asked: "what does it take to be a deck cadet on board?"

According to Cadet Lamasan, there were many challenges that he had to face while he was on board- one of them, the environment. "The first time I experienced big waves at sea and the swaying of the vessel whenever we encountered storms at sea are some experiences I will never forget (sic). It is difficult to get up and do my work. . . so that's one factor that makes the life of cadet difficult. Another difficulty that a cadet will likely experience on board is the challenge that the other crew member poses against young deck cadets like us. But the training that we had in the dormitory had really prepared us for shipboard practice. In the dormitory we were trained how to get along with other people because anywhere we go later on, we will be encountering people with different personalities, attitudes, character, culture, beliefs and values. The training we had prepared us physically, mentally and emotionally. He wants students to study hard, persevere because there is nothing easy. There is no goal that is easy to reach. A student must believe that he is capable of doing it, of becoming an officer, he could do anything including the impossible if he has the determination.

For deck cadet Borja, a cadet, especially a scholar of the Norwegian Shipowners' Association, must sacrifice a lot. "To whom much is given, much is expected" he further stressed. "The company is giving a scholarship grant and it is also expecting a good output from the scholars. To be an NSA cadet aspiring to be an officer, you really have to sacrifice and love the profession because if you love what you are doing, then it will be easy as though you are not working at all. There are a lot of challenges on board that I have to hurdle; for instance, the company pressure, second is trying to overcome fatigue because there is this big issue about commercial challenge whereby the company is expecting more so the people on board are pressured. However, these are normal activities on board. As a cadet, I have to work for 12 hours and it is part of the commercial pressure imposed upon by the company on the crew…that's the least that I have to work sometimes even 16 hours to 24 hours." (sic) There are a lot of pressures and I was thinking about giving up, but then if I am going to let myself be carried away by my way of thinking, but then it is mind over matter. (sic) It's how you condition your mind. Although there are a lot of challenges you will still be able to overcome it with prayers and as much as possible, find somebody to talk to. And after that, the problem is gone.

According to Capt. Derwin Limpiado, a master mariner in command of one of the many vessels of the Norwegian Gas Company, a cadet must have the mind-set or focus of really becoming an officer, not just because he want to be an officer but to know what the job is of a rating. "How can a cadet become an officer if he has never been exposed to the job of a rating?" he ask? "How can one supervise the ratings later on?" A cadet aspiring to become an officer must know the rudiments of the job, the routine job on deck, not just how to navigate. These things are easily learned with the advent of computer technology today. It will be difficult for a chief officer to supervise later on if he himself does not know how to tie knots or how to splice a rope.

An able-bodied seaman must be a good steering man or helmsman, and a good look-out. It is not a matter of memorizing the rules of the road, it will always be there. (sic) There are books on board that he can review from time to time. There are officers who are always on the radar. They have become technology dependent. The best way to navigate a vessel is not through the radar or any other electronic gadgets on board; it is done through visual observation through look-outs. See for yourself the situation, go to the bridge window, or if necessary, the bridge wings to assess the situation. There are new and young officers today who cannot even identify the characteristics of lighthouses, bouys, etc. The basics of piloting are still very helpful. A good steering man does not only look at the compass; he should look at the ship's head and then look at the compass only to check the heading of the vessel. It must be remembered that the compass reading is dependent upon the ship's heading. So a good helmsman looks at the ship's head and then looks at the compass to check the direction that the OOW or the Master orders to be steered.

3.1.6 *What does it take to be an officer on board a vessel?*

As the bars on your shoulder board increase, the responsibility also increases according to Capt. Angelo Lopez. "Since the position is already a management level, the chief officer is in-charge of the deck department, and all the work in this department is his responsibility. It is difficult to handle people- more difficult than any task assigned to a chief officer. You have to consider people's moods and deal with their problems at home because it affects the performance on board. You still have to deal with individual differences. No two persons have the same principles in life, the same work ethics, and as a Chief Officer I have to understand all this. It is really a matter of accepting people as they are and making the most of what they can contribute to the organization on board the vessel."

To be an officer, you must have the courage, the knowledge, intelligence and the skills and most of all you must have faith in GOD according to Capt. Rainier Salcedo. "The three stripes on my shoulder board representing my position as Chief Officer really is (sic) a big load or responsibility that an officer (sic) must carry. As the cargo of the vessel is the chief officer's responsibility, stability and trim of the vessel must be properly attended to. The life of everyone on board is dependent upon the hands of the cargo officer, that of the chief officer.(sic) An officer, 2nd officer or 3rd officer on board must always be alert especially during the time of his watch." Rainier also believed that the knowledge, virtues and values that he had learned in school is a big part of his being a captain today. He further stressed that a student aspiring to become an officer must have the courage and determination. He should aim to become an officer, not just an ordinary or able-bodied seaman. "When I took command as master of the vessel, my fear was when I gave the order "Let go all lines". It was a controlled fear within me and a temporary one. It was the signal that I am in full control of the vessel. There is no turning back, the ship will be at my complete disposition. It was temporary fear because I know I have enough training and everything went smoothly after that. I was able to conquer my fear. Capt. Limpiado considers it as his most frightening experience in his career as a master mariner. After that brief moment of fear, everything was normal and the feeling just subsided. He had worked in a gas carrier since he was a second officer until he assumed the position as chief officer at age 32, and a master mariner at age 39.

3.1.7 *The profession is financially rewarding*

"You will earn well. The higher you go up, the more money you will earn. Why? This is because captains are paid 7,000 or even 8,000 US dollars according to Mrs. Carla S. Limcaoco. While they are on leave, they are paid and the pay is more when they return on board." She adds: "I mean money is being thrown to them like it is grown on trees. And if you are done with your work at sea, you can come ashore and there will be 10,000 jobs waiting for you, here or abroad as superintendent, port captains, fleet managers, general operations managers, crewing managers, take your pick. So it is something that will start from your position as a deck cadet to the being a captain on board or ashore. It is a very special career in that sense, but very noble. It is enduring(sic) but very financially rewarding."

The profession is indeed financially rewarding, enabling the seafarers to help their families. According to one master mariner who had been to sea for 13 years in this profession, he was able to help his family financially, and he also provided some revenue for the country." Capt. Angelo Lopez also said that it is also his ambition to see the world and, being a graduate of a government maritime school, he has an obligation to return something to his country. He disclosed that his family was financially hard-up and when he started sailing on an overseas vessel; he was able to help his mother who was raising the family alone for his father had long been deceased.

Capt. Philip G. Genona, who just passed the board examinations for master belongs to the new breed of officers. He belongs to the 2nd batch of the NIS Class Project sponsored by the Norwegian Ship owners' Association. He chose this profession because of the background or his environment tells him to. Living in a town with many seafarers who are financially stable, he found himself drawn to the seafaring career. Of course he considers that besides the financial rewards the profession is giving him personally, he sees himself as a contributor to the worldwide progress of the trade.

C/M Arsenal believes that the job of a ship officer is fulfilling and also financially rewarding. Filipino seafarers today are well compensated especially at a time when there is a world-wide shortage of competent officers.

3.1.8 *On what students should do in order to realize their dreams*

"No influence from other people, your parents or anybody else, could help you but yourself. You need to have the determination, the focus if you want to become an officer, and eventually a captain like me. You have to become an officer by taking one step at a time." This is what a student must keep in mind in choosing this profession according to Capt. Limpiado.

Capt. Lopez said: "If you believe that you can survive the difficulties in this profession, by all means go for it. The seafaring profession is a noble profession, and if you decide to take this course, you must take pride to preserve the integrity of the profession, of the Ilonggo in particular and as a Filipino in general."

Capt. Philip Genona strongly advises students to enhance their knowledge and skill in computers and in both spoken and written English. "They have to know where to source the prevailing maritime regulations from and to get updates especially from the internet because they have the responsibility to be well informed. They have to be disciplined and to take their studies seriously and must do well in class.

Cadet Lamasan believed that there is nothing easy in this profession. "There is no goal that is easy (sic) to reach but it is on (sic) oneself to do including the impossible. One can make the impossible possible if one has the determination."

Cadet Borja says that there is a bright future in the maritime profession. "I know that there are many students out there who dream of becoming captains in the future or perhaps presidents of a shipping company and I want to tell them this: "Yesterday is just but a dream; and tomorrow a vision, but today well lived makes yesterday a dream of happiness and every tomorrow a vision of hope. So look to this day. If you want to have a bright future later on, you must start right now. Anything that is started right will end right. If you do good while you are in school, you will also land a good job later on. If you do good in academics, in reacting or inter-acting with people, make yourselves ready to face the challenges, I am sure you can achieve a lot in the seafaring profession which has become a very lucrative profession."

4 FINDINGS

From the discussion, the following are the findings of this investigation:

1. There is indeed a need to build the image of the profession among the youth of today.
2. Some shipping companies are already doing their part to build the image of the profession by requiring their seafarers to be as presentable as possible when reporting to the office. They go through a process of orientation where they are encouraged to become captains or chief engineers not just mere crew members.
3. This is a profession where Filipinos excel in and the chances are good for the country to its position in the world as the number one supplier of competent and qualified officers and crew.
4. The seafaring career is a noble and a challenging profession.
5. It is a lonely profession having to be away from loved ones, but it is at the same time a very challenging profession.
6. The profession is financially more rewarding than any other profession.

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15.5 Officers as prostitutes: Myth or reality? (A study on poaching of officers in the Philippines)

M. Magramo, G. Eler, J. Calambuhay & L. Bernas
John B. Lacson Foundation Maritime University, Iloilo City, Philippines

ABSTRACT: This descriptive-qualitative research looked into the reasons why a seafarer is likened to a prostitute and in what aspects they are alike. It also aimed to determine from the key informants the practices and or procedures employed by shipping and manning companies in order to fill in the much needed position on board that has become a scarcity in the last years. Likewise it aimed to determine how these manning companies keep their present pool of officers in their rooster. What are the strategies employed by the different manning companies in keeping their officers and crew loyal to their respective companies?

1 INTRODUCTION

The current shortage of officers in the world manning industry has become alarming with the estimated shortage of about 16,000 officers as of 2006, and predicted to rise to about 46,000 by 2010 according to a study conducted by Belcher, et al. (2003).

About 1/3 of the world's seafarers today are Filipinos (Amante, 2003). It is observed that a great number of Filipino officers transfer from one company to another in consideration of a higher salary.

While it is true to some seafarers that salary is important to keep them from their jobs, to some seafarers, security of the job is more important than salary. Thus, the questions is, "Is the amount of salary an assurance for a manning or shipping company to keep their officers and crew?"

During the 8th Asia-Pacific Conference for Manning and Training held in Manila last November 14–15, 2007, one of the speakers mentioned that seafarers are just like prostitutes.

But why is a seafarer likened or compared to a prostitute? A prostitute in a club goes for the guy with the most money, or the highest bidder. Likewise, Filipino seafarers today, also go to the company which offers the most money for the position.

Doris Magsaysay-Ho, chairman of Magsaysay Maritime Corporation and president of the Philippine Seafarers Promotion Council, said that ship owners who refuse to spend money on training are spreading havoc by poaching qualified crew from companies that have invested wisely (Lloyd's List, 2006). She further claimed that other ship owners have not prepared for the shortages of manpower and have been causing havoc to the market by pirating people.

The same opinion was aired by Wang (2006) and he warned that despite the ship owners efforts to train quality officers and ratings, they are under the constant threat of losing their skilled people to companies which do not invest in the training, and do not build up quality seafarers. The combination of this poaching and the scarcity of skilled seafarers had driven the salaries of some masters to $16,000 per month.

According to Chee How (2007) ship owners and ship managers must invest in the training and upgrading of the skills of the seafarers sailing on board ships to grow the pool of skilled manpower.

It is in this context that the study was studied.

2 THE PROBLEM

This inquiry aimed to determine the following:

1. What are the practices of the different crewing and manning companies in the recruitment of the officers and crew?
2. How many of the companies practice poaching? Are salaries determinants in keeping their officers and crew?
3. What other programs do companies have for the seafarers and their family in order to be able to wisely manage the allotment or even increase their monthly salary?

3 METHOD

This descriptive-qualitative phenomenological research delved into the investigation of the different hiring practices employed by the manning and shipping companies amidst the shortage of qualified and competent officers in the global manning industry. It also aimed to determine if salary is a determining factor in keeping their officers and crew. Likewise, it aimed to find out what measures are taken by the manning and shipping companies for their officers and crew to be loyal to their company.

This study utilized in-depth interviews with key informants in this research. The respondents were the different manning and shipping company managers, officers and some crew members.

3.1 *Modes of analysis*

3.1.1 *Career development plan*

Keeping their officers and crew one company which does not join the game of poaching is K-Line. As of September 2007, the company has a retention rate of 96% of their officers. It has a career development program for their scholars. They frequently visit their scholars in the different maritime schools in the country, making them feel that they are part of the company. True enough, this researcher personally attests to the fact that it is K-Line who is among the very few companies that recruit their potential officers through scholarship programs. This manner of training potential officers was stressed by the company president, Mrs. Virginia Linesis during the interview. She further mentioned that the company always looks forward to the development of its officers and crew, which means that the officers are not only trained to be competent for the present position but also for the next position. In this company, all the officers and crew have a career development program. "If you are a 2nd Officer now, you should take courses required for a Chief Officer, We even advise 2nd officers to study the job of the chief officer during their break times," said Mrs. Linesis. These researchers were happy to note that of the six (6) scholars who have become captains in their company, four (4) are from this university.

At K-Line, the career path is strictly followed. Opportunities are given, but it is really up to the crew to grab it. Some of these courses are career development, emotional quotient, psychological test and anger management.

At Philippine Transmarine Carriers, the turn-over rate is 85%. They lost some of their officers to poachers despite the fact they are giving other benefits like health and insurance plans. As part of the program on social responsibility, PTC has developed the PTC Villages, a housing development program in Imus, Cavite. Presently, there are 300 houses through PAG-IBIG Fund, payable in 20 years. Just like K-Line, PTC likewise has a career development program for its officers and crew.

3.1.2 *The practice of poaching*

On the issue of poaching or prostitution of seafarers, majority (12 of the 14 respondents) of the interviewees practice poaching. They usually assign an employee to do the hiring at the Seafarers Center near Luneta in Manila. According to a general operations manager we have interviewed: "If other companies are doing that in order to attract the seafarers, they, too are doing the same thing." Poaching is the name of the game right now according to Mrs. Linesis. This was also aptly mentioned by Surish (2007) that right now, there is a wage war in the Philippines. Wage wars are inevitable when demand outstrips supply, but wage wars do not buy loyalty. On the contrary, wage wars encourage mercenary attitude among officers, which results in company hopping. These also discourage professionalism and career development through loyalty to a single employer. According to Mrs. Carla Limcaoco, Vice-chairman of Philippine Transmarine Carriers, the word prostitutes being likened to seafarers is true. "It seems we are all scary and we are all concerned because it removes professionalism." The money according to her is so tempting. It's hard to resist. If this practice continues and younger generation will use this as work ethics, then it is indeed scary for the profession.

3.1.3 *The offers are too tempting to resist*

On the part of the seafarer, these researchers were able to interview two captains who have just disembarked their vessels. They are forced to accept the good offer because they have to be practical. The good captains told us that a seafarer is only as good as his contract lasts. What does he mean by this? If something happens to the seaman while he is taking his vacation, he will not be able to claim anything from his latest company because his contract has already terminated. After four months of the termination of the contract, a seaman cannot avail of his medical benefits anymore, unless he signs a new contract.

On other programs the companies have for their officers and crew. The Philippine Transmarine Carriers, not only has a career development program for its officers and crew, but also has a family and crew service department that focuses on the family. It conducts monthly seminar on different topics especially financial management for the wives of the seafarers. This is also practiced at K-Line. At Wallem Maritime Services, a family center which coordinates with the families of the seafarers is one of its programs. Thus, the family is always welcome to entertain any inquiries regarding allotment, procedures and vacancies in the company. This company also considers health care insurances, seniority bonus and re-joining bonus for its officers and crew.

4 FINDINGS

1. Most of the manning companies practice poaching in order to lure officers to the profession. This is the present name of the game. Demand has dictated this game due to the short supply of qualified and competent officers.
2. The prostitution of the seafarers was also dictated by the shipping industry especially the ship owners who did not invest for the training of seafarers are the ones who are now openly offering exorbitant salaries not within the reach of some ship owners. With this practice professionalism is already lost in the profession.
3. The companies that invested on the training of the seafarers are the ones now reaping the fruits of their

investment. they have very high retention rates of its officers and crew because they have effectively inculcated in the minds of these seafarers the value of loyalty.

5 RECOMMENDATIONS

The following are the recommendation of the researchers to the different shipping and manning companies:

1. Design a well-defined career development program for the officers and crew. See to it that the company takes care of the career path of each officer and crew.
2. Provide a program for the promotion of the welfare of the seafarers' families such as housing program.
3. Assist the families of the seafarers to be self sufficient through skills training programs such as entrepreneurship, etc.

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15.6
The economical emigration aspect of East and Central European seafarers: Motivation for employment in foreign fleet

V. Senčila & I. Bartusevičienė
Lithuanian Maritime Academy, Klaipėda, Lithuania

L. Rupšienė
Klaipėda University, Klaipėda, Lithuania

G. Kalvaitienė
Vytautas Magnus University, Kaunas, Lithuania

ABSTRACT: East and Central Europe countries practically experience advantages and disadvantages of seafarers‘ employment in foreign shipping companies. There is a need to investigate this phenomenon in the aspect of economical emigration. Shortage of marine officers worldwide exaggerates the shortage of seafarers in the mentioned region because of the economical emigration of national seafarers to foreign fleet, which provides more favorable conditions. These facts encouraged investigating several questions using case study method in one country (Lithuania), which social-economic conditions are similar to other countries of the region: What shipping companies (national or foreign) marine officers give priority to be employed to? What is the motivation of such a decision? What personal characteristics mostly determine this decision? The study results show very strong seafarers' attitude towards economical emigration, reveal the reasons of this phenomenon and relations with the personal characteristics of marine officers. Key words: economical emigration, seafarers, motivation.

1 INTRODUCTION

The development of global economy is closely linked to the development of maritime transport. Maritime transport is vitally important for European Union (EU) as well because more than 90 percent of EU foreign trade and 40 percent of trade inside EU is performed by sea transport (Green Paper, 2006). The development of every business depends on working professionals available in labor market: in maritime transport – on seafarers, the number of marine officers worldwide is not sufficient – 466 thousands (BIMCO, 2005).

Shipping is in the forefront of global employment, because shipping companies can recruit seafarers from "wherever the best value for money is available". (Short, 2004) In contrast to 'national seafarers' dominated in the past the emergence of 'global seafarers' could be noticed in seafarers' labor market recently (Wu & Sampson, 2005).

What is the status of seafarer employed in the foreign company? He cannot be treated as being on a business trip; he usually is employed by foreign company temporarily and comes back to his country after contract is finished. This status is called economical emigration (Ekonominės..., 2007). Economical migration is determined by economical factors: differences in wage and welfare in country of origin and foreign country. It is widely recognized that economical migration with the employment purpose (not living) is beneficial for the world economy, especially for the developing countries (World Economic..., 2004), because of the reduced unemployment and demand for social support and increased cash-flow and experience of returned people in country of origin. Short-term emigration is less harmful for the country of origin than long-term. (Lietuvių emigracija..., 2005), although it has negative aspects as well: when more people are going abroad than coming to the country; when investments to people education are lost; demographic situation becomes worse, because mostly young people emigrate; financing of social welfare declines, because tax payers went abroad, etc. (Lietuvių emigracija..., 2005), families suffer, children experience psychological, social and educational difficulties (De Silva, 2003, Лялюгене, Рупшене, 2008; Malinauskas, 2006; Nosseir, 2003; Quah, 2003).

What are the consequences of seafarers' economical emigration? Former researches proved economical benefit of seafarers' economical emigration for country of origin: e.g., Latvian seafarer working if foreign company gets salary above Latvian average and in 4–5 years returns his educational investments (Gulans, 1999); Lithuanian seafarers employed in the foreign fleet create about 60 mil. Euro added value per year while consuming and investing in Lithuania (Policy Research Corporation, 2004).

Economical emigration of seafarers is beneficial for the country-recipient; it partly helps to solve the problem of seafarers' shortage. There is a shortage of seafarers worldwide especially in economically developed countries (BIMCO, 2005); the shortage will increase in the nearest future because of high competition in maritime sector – shipping companies are reducing costs and salaries accordingly (Yamamoto, 2000; Lopez, 1989), it can be mentioned, that seafarers' salaries for West European people are already unattractive nowadays (Green paper, 2006). The number of qualified seafarers and cadets is reducing, this negatively affects maritime sector (Brownrigg et al., 2001; Gardner and Pettit, 1996, 1999; Leggate, 2004; Pettit et al., 2004; Selkou and Roe, 2002).

Meanwhile the salary offered by West European shipping companies is attractive for seafarers from less developed countries, such as East and Central European seafarers. It is predicted that in future the majority of marine officers worldwide will be employed from the less developed countries (Glen, 2008).

The East and Central European national shipping companies will face the dual problem: on one hand there is a shortage of marine officers overall and on the over hand some marine officers will be employed by foreign shipping companies because of better salaries and welfare. That is a threat for existence and competitiveness of the maritime industry of mentioned region.

2 THE RESEARCH PROBLEM

In order to understand better the mentioned problem and find practical solutions the seafarers' migration phenomenon needs thorough investigation. Some aspect of the problem already have been analyzed in China: recently the tendency towards employment in foreign companies in China is growing (Wu, 2004b; Wu, 2003); one third of Chinese seafarers prefer to be employed by foreign companies, especially – Western; 30 percent do not have any preferences, the attractive salary and welfare onboard the ship are the most important factors determining selection of the company (Wu, 2005). The discrimination in salaries comparing to other nationalities and communication problems were mentioned as negative factors of Chinese seafarers' employment in foreign companies (Wu, 2005).

Unfortunately, the researches about attitude of East and Central European seafarers towards employment in foreign companies were not found. This fact caused investigating several questions using case study method in one country (Lithuania) in 2008: What shipping companies (national or foreign) marine officers give priority to be employed to? What are the reasons of such a decision? What personal characteristics mostly determine this decision?

3 THE RESEARCH METHODOLOGY

3.1 *The sample size*

Lithuanian marine officers were under investigation. The sample selection was based on the notion that seafarer is a person holding seafarers' book (Lietuvos. . . , 2006). In the period of 2003–2007 there were 10982 such a persons in Lithuania (2003–2007 metais. . . , 2008): 7337 of them had Certificate of Competence, and 2927 were marine officers (1552 – navigators, 1375 – engineers). It was decided to make a random sampling and examine all the marine officers attending qualification upgrading courses at LMA (Lithuanian Maritime Academy) and visiting shipping and crewing companies in Lithuania in three months period. Finally, the representative (in view of age and qualifications, with 5 percent bias) sample consisting of 355 marine officers was formed (42 percent of them work if Lithuanian companies; 58 – in foreign).

3.2 *The research instrument*

The research data were collected in written form using originally designed questionnaire. Two major components matching the research aims can be distinguished in the questionnaire structure: in order to get data related to the first aim of the research, the close question with dichotomous answers (what shipping companies (national or foreign) the person give priority to be employed to?) and open questions about advantages and disadvantages of employment in foreign company were presented; in order to get data related to the second aim – several questions hypothetically treated as personal characteristics and influencing factors of the selection of the foreign company for employment were presented (marine officers were asked about their qualification, age, years at sea, salary's satisfaction, country of employment company, management level, about their opinion on the seafarer's profession perspectives in Lithuania and worldwide). Using factor analysis method 47 scales of motives of selection of seafarer's profession were grouped as personal characteristics influencing selection of the company to be employed to.

3.3 *The data analysis*

The obtained research data were analyzed using qualitative and quantitative methods. Qualitative data were analyzed using statistical analysis methods (SPSS for Windows): factor analysis of seafarer's profession selection motives; independent variables discriminant analysis of respondents' attitude towards preferences in selection of the company; Chi-square test for evaluating differences among groups; Pearson's correlation coefficient for relation's strength evaluation, descriptive statistics (frequencies). Qualitative (open questions answers) data were analyzed using content analysis method.

4 THE RESEARCH RESULTS

4.1 *What shipping companies (national or foreign) marine officers give priority to be employed to? and why?*

Despite the fact that 40 percent of respondents mentioned that they never mind in which country's

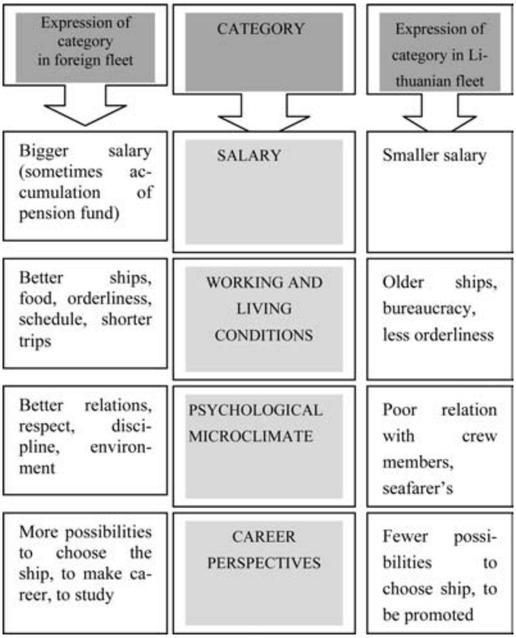

Figure 1. The reasons of prioritizing employment in foreign companies revealed by content analysis method.

company they prefer to work, answers the other question showed that the majority (68 percent) would choose the foreign company. Students' opinion towards employment in foreign companies is even stronger: according to similar research performed in 2008 with students (who are potential seafarers) 82 percent of students of marine specialties have stronger will to be employed in foreign company.

Investigation of the reasons for selecting employment in foreign or national companies by using content analysis method allowed revealing four categories (Fig. 1): salary, work and living conditions, physiological environment and career perspectives. As it can be seen in figure 1, not only economical factors determine attractiveness of foreign companies for seafarers. Working and living conditions onboard foreign ships are more attractive: newer, more technically advanced and safer ships; modern and better ship equipment; shorter time at sea; more convenient work schedule; better nourishment.

Better psychological environment in foreign companies is also mentioned by seafarers. It is described as more respectful communication with seafarers, better discipline and orderliness onboard the ships, more honest and better interrelationships among seafarers, better working and living environment.

The opinion about better career perspectives in the foreign companies noted as well, such as more possibilities: to select appropriate shipping company in the international market; to obtain higher rank faster; to learn English language; to upgrade qualification.

4.2 *What personal seafarers' characteristics mostly determine the decision to be employed in foreign company?*

Using discriminant analysis of marine officers' data the canonic function was developed, this function describes 100 percent of variable dispersion. Wilks' Lambda statistics 0.407 and $p = 0.000$ show that means of canonic function values in different groups statistically significantly differ, that indicates possibility for discrimination. Analyzing the coefficients of canonic function and structural coefficients (table 1) can be noticed that only one variable have the best discriminant feature and influences magnitude of canonic function: the marine officer's employment company. The strong correlation shows that majority of seafarers working in Lithuanian fleet prioritize Lithuanian shipping companies and seafarers working in foreign fleet prioritize foreign shipping companies.

Indication of discriminant power is rather low (table 1), but conclusions about marine officers tend to choose foreign companies can be formulated: they are employed by foreign companies now; they are marine engineers; they are satisfied by their salaries; they have chosen seafarer's profession purposefully.

5 DISCUSSION AND CONCLUSIONS

The research revealed that the attitude towards employment in foreign company prevails among marine officers (68 percent of respondents give priority to foreign company). This indicator exceeds the country's average, as it is pointed in Strategy of regulation of economical emigration in Lithuania (Ekonominės..., 2007), the number of Lithuanians willing to emigrate because of economical reasons declines: in 2001 there were 63 percent of respondents wanted to emigrate, in 2005 – 16,2 percent. Additionally it was discovered that students comparing to working seafarers have stronger desire to be employed by foreign company (82 percent). This fact matches the general Lithuanian situation: younger people comparing to older ones tend to go abroad for making money (Ekonominės..., 2007).

The research revealed the reasons of prioritizing foreign companies. The main reason of being employed in foreign company likewise in China (Wu, 2005) was mentioned bigger salary. In economically developed countries seafarer's profession loses its attractiveness because of the specific nature of seafarer's work and isolation (Study on the Supply..., 2005). Meanwhile for the people from less economically developed countries the bigger salary's issue is important (Lopez, 1989). That explains the importance of economical factor for Lithuanian seafarers selecting Employment Company.

However rising living standards reduces people's will to work in foreign companies – this is illustrated by China example: it is difficult to hire seafarers in China's shore regions, where economical boom can be noticed (Short, 2004), the number of people willing to

Table 1. The results of discriminant and correlation analysis of seafarers' data.

Discrimination variables	Wilks' Lambda	F	p	r	Coefficient of canonic function	Structural coefficient
Personal characteristics (I)						
Management level (management/operational)	1.000	.051	.822	.027	−.105	.014
Qualification (navigator/engineer)	.943	10.062	.002	.210	.388	.204
Age	.986	2.357	.127	−.184	−.235	−.099
Years at sea	.991	1.489	.224	.154	.004	−.078
Present employment company	.498	168.638	.000	.688	.991	.833
Salary satisfaction	.977	3.998	.047	.145	.040	.128
Opinion about seafarer‘s profession perspectives in Lithuania	.984	2.685	.105	.033	.269	.105
Opinion about seafarer‘s profession perspectives worldwide	1.000	.020	.886	.096	−.109	.009
Personal characteristics (II) – motives of choosing profession						
Emotional attractiveness	.994	.980	.324	−.053	−.090	−.064
Coincidence	.974	4.384	.038	−.137	.002	−.134
Economical benefit	.996	.692	.407	.086	−.157	.053
New opportunities	.983	2.819	.095	.145	.123	.108
Prestige	.988	2.045	.155	−.176	−.245	−.092
Privileges	.999	.101	.751	−.013	−.114	−.020
Influence of intimates	.999	.195	.659	−.027	−.252	−.028

study maritime professions is declining because of rising living standards. This can be illustrated also by the Lithuanian example: the country has been developing rapidly last decade, the number of students of marine specialties was not big: in 2005 there were only 550 people studying marine specialties, although Lithuanian MET institutions (LMA and KUMI) were capable to provide education for 1250 students (Senčila & Bartusevičienė, 2005). In addition there is no guarantee that graduates will go to sea, according to research in 2006 only 65 percent of students are going to work as seafarers, 21- have not decided, 14 – decided no to go to sea (Senčila et al., 2006a).

Hypothetically can be noticed that economical development of East and Central Europe will reduce attractiveness of seafarers' profession because of salary and less young people will enter MET institutions. However if the salaries of seafarers of East and Central Europe and traditional maritime countries will be similar will the seafarers choose national shipping companies? If the reason for selection of foreign company was only economical we could predict positive answer.

Seafarers' responses highlight the other advantages of employment in foreign companies, e.g. significance of psychological microclimate. Naturally psychological microclimate is important for seafarers being physically and psychologically isolated from the world (Lamvik, 2002). It was mentioned in the researches that seafarers working in foreign companies experience psychological difficulties (Dyer-Smith, 1993); since the crews are becoming multinational, multicultural and multilingual (Squire, 2006), the feeling of isolation increases because of differences in seafarers' languages, culture, education (Knudsen, 2008). Probably these psychological difficulties are lesser comparing to difficulties in national shipping companies, because the respondents mentioned that psychological microclimate is better in foreign companies.

The importance of working and living conditions was emphasized by Lithuanian research participants: foreign companies are prioritized because of better working and living conditions. It can be noted that generally seafarers' working and living conditions have been changed significantly. For example, Kahveci (2007a) investigations revealed several recent changes in seafarers' life at sea: difficulties for seafarers to come ashore (because of ISPS Code implementation); less time spent ashore (because of less time in ports); diminished usage of the facilities ashore (libraries, sport halls, excursions, cultural events), less social contacts with colleagues (smaller crews). Kahveci (2007b) has analyzed 4000 responses and determined that 64 percent of respondents during last 8 weeks was not ashore, 32 percent – were ashore for 2 hours; the majority could reach only the nearest phone-box. The possibilities of relaxation ashore reduced and accordingly the requirements to have alternatives aboard increased. In order to attract young people and sustain qualified seafarers at sea, foreign companies are trying to improve working and living conditions on board, they establish cinemas, sport facilities, saunas, libraries, etc. on ships (Sampson, 2008).

The employment in foreign companies for Lithuanian seafarers is more attractive because of the career possibilities. This fact is also proved by Swedish research (Study on the Supply. . . , 2005): because of the shortage of marine officers the companies started to hire younger and less experienced seafarers and help propose career mapping for them.

The research revealed the personal characteristics of seafarers tend to be employed by foreign company: seafarers are already employed by foreign companies; they are marine engineers; they are satisfied by their salaries; they have chosen seafarer's profession purposefully. That means that seafarers will not change foreign company to Lithuanian one. However it was discovered that seafarers working in Lithuanian companies prioritize to work in Lithuanian companies and will not change Lithuanian company for foreign one. That means that the shortage of marine officers in Lithuania will not increase because of crossover of working seafarers from Lithuanian companies to foreign ones and vise versa.

It can be mention that the number of working marine officers in Lithuania will be reduced in nearest future: they are achieving pension age, some of them are changing work profile. According to Senčila et al. (2006b) research, only one third of working seafarers are younger than 40 years, two thirds are older and will not go to sea in 10–15 years. So, the number of working places in Lithuanian fleet is increasing. That's why the opinion of potential seafarers (students of marine specialties) towards employment in foreign companies is vitally important, because they will replace experienced marine officers in near future. The similar research with students revealed that majority of students tends to select foreign companies for employment; it will negatively affect the competitiveness of Lithuanian shipping companies in future.

It is clear that investigations in several East and Central counties would allow making more reliable conclusions about marine officers' attitude towards economic emigration; however case study analysis performed in one country (Lithuania), which social-economic conditions are similar to other countries of the region, is significant, because it reveals essential inferences about the important issue for entire region.

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15.7
The role of the maritime institutions on the shortage of officers

M. Magramo, L. Bernas, J. Calambuhay & G. Eler
John B. Lacson Foundation Maritime University, Iloilo City, Philippines

ABSTRACT: This study aimed to determine the role of the maritime institutions in the midst of the shortage of officers in the world manning industry. The quality of instruction and the competency of the professional instructors are seen as an important factor in producing quality graduates who will eventually become officers to man modern ships of today.

1 INTRODUCTION

Several studies indicate that there is currently a worldwide shortage of officers, corresponding to 4 percent of the total officers (16,000) and the prediction is that by 2012, the shortfall will rise to 46,000 (Kumar, 2007).

The shortfall of seafarers has a negative impacts on the shipping industry as a whole; whereas both the on-board and on-shore maritime related work posts face manning problems that may directly threaten the existence of shipping activity and the sustenance of maritime know-how (Chaterjee, in Kumar, 2007).

Japanese shipping companies plan to hire 10,000 seafarers from the Philippines between 2008 and 2010. (http://www.gma.news.tv/). This was stated by the president of the Philippine-Japan Manning Consultative Council, Mr. Eduardo Manese. He further said that Japan will increase its merchant fleet of 2,223 as of 2006 to 3,000 by the end of 2010, and further to 4,000 by 2015.

The same opinion was shared by Ambassador Stale Torstein Risa of Norway during the two-day International Maritime Conference hosted by JBLFMU last January 29, 2008. He encouraged maritime schools in the country to give importance to quality-based maritime education and training to meet the demands of the global shipping industry. Risa noted that most of the world's global trade is by sea and that globalization has entirely changed the world's trading patterns with new emerging markets requiring more transport services than ever before. Aside from the expanding off shore exploration of petroleum resources the cruise industry also continues to grow. This entails a growing demand for maritime workers. He further stressed: "I believe schools should even seek to follow-up and evaluate their graduates' employment experiences. They should keep track of their graduates and to get feedbacks after spending [SIC] some time at sea and it would be a valuable input in determining if the level of training is adequate, and even offer advice on issues such as job satisfaction."

Indeed the maritime schools today play a very important role in the production of quality of graduates, thus this research.

2 THE PROBLEM

This study aimed to determine the role of the maritime schools in helping to solve the problem of seafarers' shortage.

3 METHOD

This study utilized the descriptive-qualitative method of research. It employed a historical – narrative approach, using an in-depth interview of the key informants. The participants in this study were the managers of the manning companies and the various representatives of the owners of the shipping companies in the Philippines.

3.1 *Modes of analysis*

"The schools are the producers of seafarers." These are the words coming from the lady president of K-Line Maritime Training Center, Mrs. Virginia Linesis. She also stated further: "The competencies of the new graduates are always questioned. One of the issues is the competency of the teachers. These teachers have not recently disembarked from the vessel. So, their knowledge and skills as far as new vessels are concerned are not adequate to teach these students. Teachers are not updated. The competency of the supply at the end of the three (3) academic years of the students is always questioned by the industry. For a company like K-Line with a training center, we augment whatever inadequacy in the skills of the students by giving them the training necessarily required in the type of vessel they will be joining. As far as this company is concerned, we don't assign any anybody on board unless he is trained and ready for the job because the confidence of the seafarers even if he is just a cadet is important when he goes on board. He should be able to know the job required of him. And to those with no training center, that would be a very great factor.

She added: "The problem before was always the engine shortage on the engine department. At this point, this is gradually addressed by the school. There must be a balance. The reason for this is that there is a need of a 'bridging program', in order to augment the shortage of the supply in the engine department especially the engine officers. K-Line is the first company to initiate or introduce the bridging program (mechanical engineering to marine engineering) because [SIC] we are now in the third year. In 2005, we had the first batch of 18 marine officers."

Before putting up the training center, Global Training Systems, Inc., of which he is president, Capt. Jose Martinez, a research master mariner, had this to say:

"The instructors are the sole instruments on the education of the students. It is from them that the students hear everyday. In [SIC] everything that they do they must do it well and learn to love it. If they love what they are doing, everybody they shared with [SIC] will also love what you are doing. They have to inspire the students; always give their best in teaching. The English language is very important because this is needed in the profession. Even when students are good in doing the job it is necessary to explain the what, how and why it needs to be done. If you cannot express yourself in English, then it might lead to serious consequences. But if you are conversant in the language then you have an edge."

Mrs. Brenda Panganiban had this to say: "I believe that your school has some qualifying examination. I think that your school should also administer an aptitude test for the marine profession so that you will be able to determine who among the current students are fit to continue in the course. Maybe it can be done after one year, after taking a general course just like in the nursing or medical profession. [SIC] The minds of the students in the higher level now who passed the aptitude test must be conditioned that they are educated and trained to become officers. [SIC] They should be guided in the way they talk; act, and interact with people. The character, the attitude and the whole personality must be developed. In school it must be emphasized that to become an officer you maintain humility regardless of how far you have gone or become. It is also important to develop the spirituality of the students because when your spirit is strong, your mind and body will be strong as well.

Mr. Ericson Marquez, President of Pilipinas Crown Maritime said: "The source of knowledge will be the schools. But if you continue to produce less and less competent graduates, then 20% are only qualified. Then, 'wala tayong pupuntahan talaga' (we are going nowhere). What is our response? Last year, we did an assessment (MSAP-Maritime Schools Assessment Program). We know which schools can produce how much. We know some school cannot even produce a single applicant to pass our standard. Our standard is not very high. We use criterion reference in establishing the standard. Last year we had a pilot test on this activity. This [SIC] February1 and 2, we expect that CHED will issue a memorandum for all the schools to participate. Last year JBLFMU did not participate for you had an activity on that day. [SIC] We hope this year you will participate, not that we doubt the quality of your students but we are using the better schools as the benchmark for other schools. Last time we used MAAP as our benchmark, MAAP participated. [SIC] The ninety-four students of MAAP were all on top, only 1 or 2 were not in the top 100. You can imagine how many percent it is as against 56 scholars who participated."

He also narrated: "Last year, we did not promise any incentive for those who performed well, but this year we will. We have already obtained 200 scholarships from OWWA at Php 30,000 each scholar. So, its [SIC] 30,000 each for 100 deck cadets and 100 engine cadets. The grant will be given on their third year. This money will not be paid to them. They cannot be a grantee if they are not a relative of a seaman or they have contributed to the fund. Our agreement is to get the 200 scholars and will [SIC] pay the contribution. Later, the OWWA will refund us. This is open to everybody except for MAAP, PMMA and NSA cadets. This Php 30,000 grant will be added with incentives because we were able to convince Japanese ship owners. We are telling the schools, on the basis of the assessment as endorsed by the Commission on Higher Education (CHED); they can prepare a program to prepare them as ratings instead of an officer. They must be taught cooking, ship painting, ship maintenance and welding and make them the best ratings that we can produce because we need ratings. [SIC]"

He also said "We are not criticizing the schools; the problem is not only in the collegiate level. It starts from the elementary schools and high schools. If somebody from high school cannot add fractions, there must be something wrong. But some of these schools will still accept them as freshmen in college. Now, how can they run ships if they don't know how to add fractions or solve for the volume of an object? This is what we are pushing, but certainly some schools may not like it. This is what is happening and everybody must wake up. We are trying to unify our efforts in the four organizations in the manning and crewing industry. Maybe it's now time that the maritime schools join [SIC] hands in solving the problem of the deficiencies of the graduates in order to help solve the problem on seafarer shortage."

Mrs. Carla S. Limcaoco, the vice-chairman of Philippine Transmarine Carriers had this to say to the maritime schools: "Look at the curriculum. Look at the issue of its relevance in today's world. There are certain subjects that are non-negotiable that students have to study. But are they relevant?

4 FINDINGS

1. There are schools which produce graduates that do not necessarily meet the requirements of the industry. Hence, there is a need to improve on the quality of instruction especially on the professional subjects. Most of the professional instructors are not updated on the latest technology on board and as such, the instructors' delivery is short-changed.
2. There are aspects of the curriculum which are not relevant to the present needs of the industry especially with the fast changing phase of technology development.
3. There are youngsters today who prefer other courses that are equally financially rewarding as seafaring.
4. the school should motivate the students to become officers not just be contented as ratings.

5 RECOMMENDATIONS

1. The schools should intensify the supervision of instruction among the professional instructors.
2. The schools need to review their curriculum especially its relevance to the current needs of the industry.
3. The schools should be more selective with the new entrants in the course or program.
4. An aptitude test must be implemented to the second year level to determine if the students are fitted to be seafarers.
5. A continuing evaluation program should be initiated among the students to ensure that quality learning is achieved.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

15.8 Psychological features of seamen's activity in emergency situations

V.A. Bondarev & O.M. Bondareva
Baltic Fishing Fleet State Academy, Kaliningrad, Russian Federation

ABSTRACT: The rendered material will help to form a clear view of psychological features of human activity in situations concerning increased danger to a person's existence.

Emergency situation causes very high psychical overloads, special emotional conditions of psychical mental tension which can be determined in such terms as "stress", "affect", and "panic".

In an emergency situation the crew's activity becomes more complicated due to such psychological factor as "fear of making mistakes". Under the developing emergency conditions legal and moral responsibility for prompt and correct actions is increasing. Untrained senior officers and crew members might have the "fear of making mistakes". They might think that their wrong actions and decisions could cause material loss and casualties. The "fear of making mistakes" doesn't allow them to make right, informed decisions and efficient countermeasures in case of emergency.

Fear limits, obstructs, immobilizes. It is notable that Honoré de Balzac who was the master of the human soul wrote in one of his novels:" Under the influence of fear all human abilities either achieve extreme exertion or fall to decay."

What is fear? It is an emotion (feeling) arising in danger to biological and social human well-being. It doesn't matter how real the danger is. It could be an imaginary danger. The main point is that the person who is frightened would take it for real.

Passing through fear varies in wide range of gradations: diffidence, apprehension, fright, panic, terror. It depends on the situation and on the individual peculiarities of a personality. In cases when feeling the fear achieves its affect it imposes some stereotypes formed in the process of biological evolution of so-called "emergency" behavior upon a person. In other words the mind switches off at that moment and the person acts as "being beside him (her) self" in the exact meaning of the words. But unfortunately, the actions themselves nearly always turn out to be irrational, very often they lead to deplorable consequences.

The behavior and internal sensations of the frightened people are different. Fear makes people tremble, squeal, scream, cry, laugh…It butterflies in the stomach, hands and legs tremble, it dings in the ears, there is a lump in the throat, the face becomes pale, heart pounds, you have heavy breathing, your hair stands on end, pupils of the eyes enlarge, you feel tingles down the spine. Fear makes you run no one knows where at breakneck speed, stand motionless staring fixedly and blankly in front of yourself, or, excuse the naturalism, defecate... It is necessary to classify the gist of a person's reactions to understand them.

People feeling fear have the following mental states: agitation (expressive symbol is escape), stupor (expressive symbol is torpor), clouded (twilight) state (expressive symbol is uncontrollable aggression). Just escape, torpor or aggression are stereotypic ways of the "emergency exit" in such situations when a person cannot find the acceptable way out.

Agitation is the most commonly encountered. It is expressed in trying to escape, hide, not to see and hear of what is frightening. In motions agitation motivates people take some automatic defensive actions. For example, he closes his eyes, humps shoulders, covers his face and body with his hands, leans to the ground, springs back from the source of danger, runs away. Serious changes take place in the organism at that time. Under the influence of such hormone as adrenaline big volume of blood moves to the organs ensuring human movements, generally to the legs. Blood leaves the other organs at that time, especially the brain. That is why cerebration becomes worse and a frightened person does not often know where to run.

Increasing of the adrenaline level in the blood of mentally unstable people has a feedback action: it paralyses their muscles. It is also a natural reaction, developed evolutionary: pretend to be dead not to be hurt since no carnivore would eat carrion. And in the battle people usually don't hurt the fallen.

Stupor is expressed in freezing or in very slow and awkward human movements and even a person can fall unconscious. It happens since the muscles contracted convulsively and their blood supply shortly became worse, human physical coordination changed.

Clouded (twilight) state is expressed in lapses of memory (a person does not remember what he has just done), alogism of cogitation, emotional overexcitement. Externally, clouded state looks like a madness attack, inconsequent or insane aggressive actions towards the fear source.

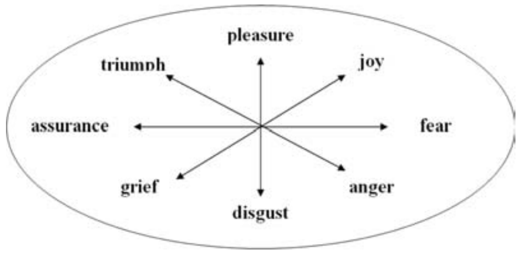

Figure 1. The scale of emotions.

But it should be mentioned that full-featured aggression as a fear expression is less common. On the other hand its attributes are well-known: malicious face expression, threatening gestures and pose, scream or squeal. They are based on an instinctive intention to frighten the rival; sometimes it is successive sometimes not.

So fear makes a person weaker, paralyses or, figuratively speaking, makes a person get into hot water, but it is well-known to be useless. That is why there is no use to hope for the victory in the conflict with a stronger enemy unless you are not able to control your emotional state.

In modern psychology there is a conception according to which the endless variety of human emotional life is determined by some basic emotions. Each of them has its own valence. According to the valence index there are four pairs of basic emotions opposed to each other: pleasure- disgust, joy-grief, triumph-anger, assurance- fear. The scale of emotions is not linear but circular. Schematically it is as follows (fig. 1)

This scheme vividly confirms the rightfulness of the traditional emotions' distinguishing into positive (sthenic) and negative (asthenic). The former encourage inspiration, provide some energy for a person and increase his will activity. The latter weaken the will, decrease activity, predispose to passive defensive actions and worsen the organization of behavior. Therefore, a psychologically trained seaman's positive emotions should always dominate over the negative ones.

In accordance with the same conception emotional states could be distinguished into short-term and long-term. The former are direct reactions to certain situations. The latter (they are often called feelings) are determined not only by the exact moment but also by the past and future of the human's life. For example, envenoming somebody's life feeling of fear could be associated with a by-past danger or with the thoughts of the coming death. Situational emotions of fear and fear itself as an essential feature of a personality have one basis. It is very important for seamen's psychological training. This basis is a feeling of impendence of death, the end of existence. That is why everything which could directly or indirectly lead to death (even if it is only in the imagination of a person) is the cause of the fear emotion. It should be also noted that a person with dominating asthenic emotions stronger and more often feels fear than an individual with dominating positive states.

Any danger or aggression should stir up positive (sthenic) emotions but not the feeling of fear at a well-trained seaman. To put it into practice it is necessary to solve two main problems during the process of seaman's psychological training:

– Dispose of a death feeling.
– Learn to act unconsciously with your brain on autopilot in emergency situations.

Then in any situation even in the teeth of death a person will be able to act freely, without any tension, using the most effective way for his abilities. Even at the limit of his abilities.

To cut the long story short, the first problem can be solved by personality programming (including self-programming); the second- by visualization (meditation) and autohypnosis. Let us study both ways in greater detail.

To dispose of a death feeling forever it is necessary to change your own personal scale of values. If your life is considered to be the most valuable thing then whiplash of fear in emergency situations will be practically unavoidable. In other words, it is necessary to have an idea which could dominate over the animal self-preservation instinct. People understood it long time ago. It is no mere chance that Japanese samurais had an authentic death cult.

Eternal samurai's enemies (ninja) practiced the techniques of psychological training focused on the realization and experience of future death. The realization and experience of future death in particular are connected with ritual admissions in religious sects and organizations of different times and countries. To feel the death, fathom its mystery it is necessary to stop being afraid. Not to make some other people believe that you have no fear, but dispose this emotion out of your psyche.

Stopped depressing the human consciousness, the thought about death gives the possibility to feel strong zest for life, it enables to enjoy every moment delicately.

Being in chime with natural development and with him/herself, a person could get the ability to live tranquilly. "To live when it is rightfully to live and undauntedly die when the moment comes". Different ideas allow not fearing death. Such concepts as family's honor and personal duty at his lord played an important part for samurais. Modern Europeans have some other key concepts. For example, self-respect, family's duty, service to a political organization etc.

A person adopts different norms and values during his life (badly- well, beautifully-ugly, right- wrong, decently- humiliatingly etc.) That is programming giving common direction to human's ambitions and certain life perspectives. It is clear that environment: parents and neighbors, teachers and tutors, friends and acquaintances, colleagues and occasional fellow travelers play the main part in programming. And of course books and magazines, films and television, rumors and fashion. To make a long story short, we are spontaneously programmed by a giant information channel which passes through our psyche during our life especially in the childhood and adolescence.

Speaking about self-programming we mean the attempt to regulate this process, make it more or less goal-oriented, successive, and systematic. That is why we need a doctrine (political, religious, moral- it does not matter). It gives a person some support in his/her thoughts, enables to judge and choose, shows the way, and lights the way with the highest meaning. In the context of the discussed problem it is extremely important that such doctrine should admit and justify self-sacrifice in the name of the values and norms accepted by the person.

A person should not only "know" that he/she must not be afraid of death and there are some things which cost more than a life but he/she should make this idea a part of him/herself. It is essential to transfer this idea from the sphere of consciousness into the sphere of unconsciousness. For this purpose it is necessary to make up a list (a programme pack) of certain "orders" to our biocomputer. Such orders must be short, clear, in the form of positive statements.

In other words the "programme pack" is a special "code of courage". (We could recollect "honor codes" of the traditional schools here.) It is necessary not just to learn it by heart but insert it into the unconscious sphere of our psyche. There is a very interesting phenomenon: this programme starts working independently of our consciousness if it was inserted correctly. That is, programmed behavior is implemented in an emergency situation by itself, without any vivid will interference and without any violence against a person.

Generally speaking, fear can be disposed using two ways. The first one, which was mentioned above is the depression of the animal self-preservation instinct by means of mind's logic. The second way of fear disposing is to switch off the consciousness and act with your brain on autopilot. In this case a properly trained unconscious sphere of our psyche completely ignores danger and it is not afraid of it for that reason. Theoretically, both ways should make a junction. Then a person even being in a desperate situation would act freely, easily, self-confidently. Moreover he/she would have such possibilities of which he/she could only dream in his/her real life. However, super possibilities enabling to "move mountains" do not just come at will. A long, persistent, very hard training is necessary. In connection with the above mentioned we will look upon a simple but very important scheme (figure 2). The meaning of the scheme is the following it shows how to learn to evolve from a human being into someone else: a beast, a robot, a superman, an "Angel of Death"- into anybody. Assimilating with an image, fitting into it you will act with your brain on autopilot, without any fear, using self-programming and meditation.

At first it will take much time, but achieving a higher training level the stage of fitting into an image will reduce from several hours to some seconds.

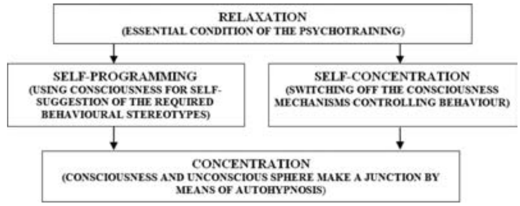

Figure 2. Psychotraining scheme.

But why should we "switch off" the consciousness? Let us see the other side of the discussed problem in the mental sphere for better understanding. Illiterate people often confuse mind and consciousness (they perceive themselves as creatures separated from the environment), they mix mind and intelligence (which is only a structure of mental abilities). Animals and morons have mind as distinct from consciousness. The point is- what kind of mind it is.

So mind is an operation of information processing, coming into the brain through the sensory organs (sense of sight, sense of hearing, kinesthetic sensation, sense of smell), and also from the inside of the organism. As a result of the processing our biocomputer (central nervous system) gives orders in the form of impulses, passing through the neural network and regulating all our motions, actions and conduct.

Three mind types are distinguished.

– Visually operative- based on the intensive and varied manipulation of your own body and surrounding objects.
– Visually creative- based on the emotional and sensual apperception of the objects and events "inside" and "outside" the organism.

Abstractedly logical, conceptual, sign-oriented mind based on the reflection of the cause-effect relations, associated with the recollection of the past, knowledge of the future and self-awareness.

It is clear that visually operative and visually creative mind types comprise an animal stage of the human psycho development. But at the same time both mind types the most significant for close-handed fight. Abstractedly logical type is rather an obstacle. In connection with the said let us consider a question of encephalic asymmetry in detail.

It is identified that psychological functions are distributed between the right and the left cerebrums. The function of the left one is to operate the verbal and sign-oriented information and also reading and counting. The function of the right one is to operate images, space orientation, coordination of movements, identification of compound objects (for example, faces, figures, colors etc.) In view of the fact the difference between the cerebrums is not determined by the material they get from the sensory organs, but by the way they use (process) it. The left cerebrum is responsible for the abstractedly logical ways of processing; the right one is responsible for the visually creative and visually operative ways. The left cerebrum operates both discontinuously (discretely) and sequentially (gradually). The right cerebrum processes information synchronously (simultaneously) and synthetically, immediately grasping numerous features of phenomena taken as a whole, undifferentiated.

To understand the possibilities of the goal-oriented training (also psycho training) it is necessary to know that an encephalic asymmetry is put in a person only as a precondition, it is finally formed and corrected by real living conditions, education, upbringing.

From the said above (about mind types and encephalic asymmetry) we can clearly conclude that for surviving in an emergency situation a person should activate (enhance) the functions of the right cerebrum and weaken (inhibit) the activity of the left. We will remind you one more time that the right cerebrum is responsible for the position of the body and space orientation, speed and coordination of movements. The experience of any situation with its space-temporal characteristics is also carried out by the right cerebrum the operation of which enables a person feel him(her)self "here" and "now", in a certain entity at the given moment.

That is why enhanced activity of the right cerebrum, its domination over the left, so to say, expands the inner sense limits, "prolongs the moment". Externally it is expressed in speeding-up body's response reactions. The thing is that on the abstractedly logical (verbal) level the mind manages to process not more than 100 bits a second but on the visually creative and sensomotor (operative) levels – up to ten million bits! By means of it the "body's mind" free from the "intelligence's chains" starts the motor response practically in seconds. Therefore a well-trained seaman really acts earlier than he manages to think about it.

However, our biocomputer is able to make a certain choice of those actions which are "encoded" in the psyche. Frequent repetition and training (i.e. exercise in similar but different in detail situations) are necessary to insert them there. In other words automatic behavior in emergency situations demands preliminary practice of some definite "clichés" (matrixes). A trained person can "give away" such clichés just right after the general identification of the situation nature.

It is known that it takes the right cerebrum only 60 milliseconds to recognize the situation; meanwhile, pixel-by-pixel analysis (the left cerebrum operation) takes 320 milliseconds. But if, for example, two events follow each other with an interval, which is less than this figure then a person is physically unable to react adequately to the second one. Therefore a delayed response is unavoidable every time he (she) tries to understand the situation in detail. And vice versa a seaman is able to give away a response action in the shortest time period recognizing the situation in general (without thinking) on the basis of the preliminary practiced and "coded" schemes (clichés, matrixes) inserted in the subconscious mind. That is a non-conceptual, automatic, intuitive cogitation of a professional.

And it is necessary to add that the dominance of the right cerebrum reduces sensitivity to pain, weakens criticism in the analysis of the reality. Evident response to a real danger decreases accordingly, up to absolute defiance. If such a state overlaps the noninvolvement to death, readiness to fight to the last (it should be guaranteed by self-programming), then extraordinary fearlessness comes up. At that time a person pays attention to nothing except the thing which is directly relevant to the developing situation. But everything coming from the danger even poor signals is conceived highly sharp.

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Chapter 16. Maritime education and training

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16.1 Maritime education – putting in the right emphasis

A. Ali
Bahria University, Karachi, Pakistan

ABSTRACT: Education is the first step towards the effective and efficient utilization of the available resources. Same is the case with maritime sector and industry. Our maritime cluster is handicapped with respect to the educational needs and their fulfillment. We need to come up with institutions of world ranking for maritime education. Whether it is port sector or shipping industry, coastal zone development or environment protection, what we need is to have means to educate our people for all tiers and types of organizations in maritime domain.

1 INTRODUCTION

When judged with respect to available economic resources and opportunities, it will be justifiable to call our planet ocean in place of earth. Access to sea and having a coastal zone enriches a nation to such an extent which is beyond the grasp of so many littoral nations. We have to literally educate our masses and policy makers to have the right direction in their future planning and nation building and attract investment in the maritime sector.

Education and awareness is the first step towards the effective and efficient utilization of any opportunity you may have within your reach. Same is the case with maritime sector and industry. Our maritime cluster, to much extent, is handicapped with respect to the educational needs and their fulfillment. We have remained dependent for too long on seafarers' practical knowledge and expertise for employment in shore sector. Like other areas, we need to come up with institutions of higher education for maritime industry. Whether it is port sector or shipping industry, coastal zone development or environment protection, what we need is to have means to educate our people for all tiers and types of organizations in maritime domain.

Purpose of this paper is to discuss, and critically analyze how important it is for a country with maritime potentials and opportunities to promote maritime education for the development of national economy; what are the various factors and limitations that hamper the promotion of maritime education vis a vis the other faculties; and finally, what should be the modus operand for giving impetus to existing efforts for much desired promotion of maritime education.

2 BACKGROUND

Pakistan is a large and diverse country having all types of topography with jurisdiction over large Exclusive Economic Zone (EEZ), proudly called the fifth and the largest province of the country. The economic activities that relate to this fifth province are numerous in existence and much more in pipeline. The country's economy is dependent upon sea transport for its key exports – raw materials and agricultural commodities – and imports, mostly manufactured goods. Almost whole of the Pakistan's trade in goods is carried by ships. Coastal shipping is also going to rise in importance with the planned development of the Gwadar Port and Coastal Belt of the country.

The marine space also provides a wealth of resources: minerals such as oil and gas, living marine resources and tourism/recreational resources. It is increasingly recognized that the development and use of marine resources needs to be undertaken in an ecologically sustainable manner to ensure that they remain available for future generations. It is also critical for the industries that operate in the marine environment to do so in a way that minimizes their impact upon it.

Oceans and coasts are also important in cultural and social context. Pakistan has a rich maritime history and heritage. Largest city of the country, namely Karachi, is on the coastline housing largest port structure, shipping activities and related industrial complex. A large portion of our population live beside or close to the sea or travel to the seaside to relax, and percentage of such people is going to rise in near future with new port structure and coastal development in the plans.

The industries that operate in, or are dependent upon, the marine environment are critical to the well-being of coastal or maritime communities. These industries also make a significant contribution to our national prosperity and growth.

3 CAPACITY BUILDING

Success of the maritime sector is totally dependent on a skilled, highly qualified and motivated human resource at all levels. There is an acute shortage of trained and qualified workforce and managers for maritime sector and industry with reliance on sources of expertise from other industries.

3.1 *Maritime Cluster*

First of all we need to identify what we mean by the Maritime Sector (Cluster). Various sectors of the maritime industry, which collectively form what is known in some countries as the Maritime Cluster, are probably the most diverse and varied within industrial sectors. These include but are not limited to port authorities, stevedore companies, labour suppliers, maritime insurance, maritime administrations, shipping companies, classification societies, ship-building, maritime legal consultancies, maritime security agencies and coast guard officials.

Most of these sectors benefited in the past from an inflow of well educated, disciplined practitioners, namely seafarers, who after serving at sea for a number of years, would come and take shore-based positions.

3.2 *Expansions and needs*

Use of oceans has expanded much ahead of shipping and new areas of study have evolved like environment, sea-bed resources, fisheries, marine biology, coastal zone management etc. Associated professions like port management, shipping management and international law require dedicated experts and scholars. New world order demands new emphasis on issues like marine security, terrorism, piracy and maritime fraud to ensure world peace in 21st century.

In Europe, research studies funded by the EC indicated that in addition to technical subjects that employers identified as essential for their sector, they also identified a number of core skills that they regarded as important for their staff to be employed in shore based industry. These included organizational/analytical skills; customer awareness; communication and interpersonal skills; environmental awareness; safety and security; leadership and teamwork; and advanced IT and e-commerce.

It is widely recognized that most of the sea-going officers leave the sea at a certain point in their lives to take up employment ashore in a marine related job. This is the time when they need certain type of education and training so that building upon their sea experience, they can make themselves suitably qualified for the shore based maritime industry.

Shore based maritime sector benefited from the experience and expertise of the ex-seafarers employed in various capacities. Employers in some of these maritime sectors feel that their future is threatened by a skill shortage. Concern about the number of available former officers suitably qualified have sparked a series of research projects which have culminated into multiple governmental actions and industrial led initiatives aimed at buoying up the number of seafarers working in the industry.

3.3 *Problem in hand*

Measures to support the skills base have been inextricably linked to research into the state of the labour market for marine skills. This market is chiefly composed of former deck and engineering officers, predominantly from the merchant marine.

3.3.1 *British experience*

Shortage of experienced and suitably qualified officers can be seen as starting with the first empirical research into the problem by Moreby and Springett's (1990) "Critical Levels" study. Close to follow was the work carried out at the University of Warwick, on behalf of, among others the ISF and BIMCO.

The British Chamber of Shipping Report, "Britain's Maritime Skills" made some projected estimates for the future of the numbers of officers, both ashore and at sea. This has been recently updated by a report "United Kingdom Seafarers Analysis 2006" conducted for the Department of Transport, which has alarming indications for availability of maritime skill base in the future.

In UK, the Report of Proceedings of the Committee investigating "The future of maritime skills and employment in the UK", and "British Shipping: Challenges and Opportunities" contain evidence indicating the decline trends in maritime sector and the implications of such developments. The Employment Committee Report (1993) contains submissions from people in the industry voicing their fears concerning the shortage of people to work in the UK shoreside industries. In particular, evidence can be seen being submitted by various shipping industry related organizations and bodies to a government committee insisting that it is essential that certain key jobs in the shore based maritime industry are carried out by former seafarers for various reasons, and they need to be suitably qualified to undertake these jobs.

3.3.2 *Australian experience*

Numerous studies over the past decade have been conducted indicating a similar pattern in Australia to that of the United Kingdom. Two publications can be referred; firstly the report by Capt Denis Parson, "Maintaining Manpower and skills requirements for Australian Ports" and second is a document reporting the Senate enquiry into "Workforce challenges in the transport industry".

The first report has examined the skill shortages and their causes. Report indicates skill areas which will make seafarers more transferable to maritime shore based sectors and that included logistics and supply chain management; Information Technologies (IT), and E-business skills; organizational, HR, and management skills; port and terminal management skills; maritime policy and strategic development skills; marketing, commercial, contract and negotiation skills; and finally health, safety and environmental management skills.

Of interest here are extract from various submissions to the Senate enquiry on "Workforce challenges in the transport industry" as follows:

Australian Ship-owners Association (ASA) submitted that it is clear that the maritime industry faces a number of challenges and issues with regard to employment and training. These included lack of awareness and industry profile with existing initiatives having a negligible impact in the maritime industry. ASA also said that while the industry is taking pro-active steps to address the skills shortage, opportunities do exist for other stakeholders, including Governments, to take a more active role.

Australian Maritime College (AMC) submitted that future of Australian economy, national security, and defence is dependent on well trained and high quality maritime human resource, to support both the "sea going" and "shore-based" maritime industries. Based on this, AMC recommended in her submission that the Australian government needs to consider offering additional fee support or fee waivers to encourage young Australians to undertake Maritime Education and Training (MET); and develop well focused initiatives to maximize training within the maritime industries.

Maritime Unions of Australia (MUA) submitted that Australia's maritime industries are continuing to expand in response to growing container trade particularly imports; growth in the export of bulk commodities; and growth in offshore oil and gas exploration, construction, production and transportation.

3.3.2.1 Remedial measures

The twelfth report of the Environment, Transport and Regional Affairs Committee, "The future of the UK shipping industry" published a summary of the committee's findings and was also based upon "British Shipping: Charting a New Course". The committee agreed among other things to establish the importance of shore-based shipping services in UK. After considering the submissions made by various bodies, the committee found that a successful shipping industry would bring many benefits to the UK in terms of income and employment, as well as for strategic and political reasons. They concluded therefore that there is a strong case for supporting the industry.

The strategy adopted in UK was two pronged: a marketing strategy aimed at increasing awareness of maritime careers and to make information more readily available; secondly to widen access to training opportunities and increase the value of officer's qualifications to increase their suitability for absorption in shore based industry.

Better career marketing approach has crystallized into marketing campaigns aimed at promoting shipping to the public as well as to decision makers. The Chamber of Shipping, seamen's unions and some other similar organizations have promoted a number of initiatives to increase the profile of shipping in the UK. One such initiative is the "Fighting Sea Blindness" campaign, which aims to help promote co-ordination of various groups' efforts in relation to maritime issues and employment.

More specific measures included the production of careers videos, posters and information packs for distribution at schools and co-ordination of several web sites, which feature information and links concerning maritime careers and maritime industry. This also included planned attendance of the MNTB at career exhibitions and fairs. These events have also been supported by maritime training colleges.

Project Sea Vision was launched in January 2003, promoted by the UK Chamber of Shipping. This initiative aims to raise first of all awareness of the maritime sector in UK, and its importance in the country's economy; and secondly to generate interest in a range of marine careers. Sea Vision does not specifically relate to shipping and shipping related industries. It encompasses other marine sectors such as ship and boat building, marine leisure, defence, fishing, environment, commerce and so on. The initiative draws together regional and specific centers of expertise in promotion and education. These aim to generate and disseminate career materials to relevant targeted areas, and to provide a public relation vehicle by attending specific public events.

As part of a number of measures taken by the UK Government to support an increase in cadet numbers, it has supported the creation of the Maritime Training Trust by the industry. The trust provides a central point for the receipt and administration of the industry's financial contributions towards supporting further seafarer training. The concept of the trust was that companies could voluntarily contribute to the costs of training seafarers through donating money to a pool, rather than making any direct training investment themselves. This scheme was also aimed at shore-based maritime companies who employ former ships' officers.

4 DISCUSSIONS AND CONCLUSIONS

Maritime sector has its own set of problems and industry should be aware of skill shortages in the sector and the need for capacity building. These issues have been raised and discussed at different forums; however, there is a lack of a coherent policy, and work program to address these issues.

There are a number of groups and networks actively working on addressing these issues. These activities however, are not coordinated and in isolation from each other, at times creating confusion and duplication of efforts. Perhaps the best way forward would be either a "network of networks" or recognition of one of the groups as the leader.

The turning point for the United Kingdom was the realization of the situation by the UK government, which followed be a raft policies and actions involving the whole of industry, government and other stakeholders. That is what needs to happen at other places also to put the things at right track in maritime industry.

Pakistan needs to learn from the experiences of other countries like United Kingdom and Australia and has to realize the importance of new emerging study areas linked with maritime industry. We need to educate our young generation in professions like environment, insurance, law, security and financial management linked with maritime sector. Only through these measures, we will be able to maintain our pace of progress and expand our operations in maritime industry.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

16.2 Correlation between academic performance in Auxiliary Machinery 2 subject and navigational trip among marine engineering students at maritime university in the Philippines

R.A. Alimen, V.B. Jaleco, R. L. Pador, & M.G. Gayo, Jr.
John B. Lacson Foundation Maritime University-Molo, Iloilo City, Philippines

ABSTRACT: The purpose of this study was to ascertain the level of academic performance in Auxiliary Machinery 2 subject and navigational trip among marine engineering students at maritime university, specifically JBLFMU-Molo, Iloilo City, Philippines. It further aimed also to determine the relationship of the two variables. The researchers used the quantitative research method and employed the descriptive statistics for the analysis of data among the randomly selected participants of the present study. The statistical tools were frequency, mean, and Pearson's r. To come up with the data needed for this study, the questionnaire – checklist on "Navigational trip" was developed by the researchers. Results revealed that as an entire group, the level of academic performance was "excellent" and the navigational trip was "moderately satisfactory" among marine engineering students. The correlation between navigational trip and auxiliary machinery 2 subject was "positive and significantly correlated."

1 BACKGROUND AND THEORETICAL FRAMEWORK OF THE STUDY

Navigational trip is a subject in marine engineering, which the students undergo in partial fulfillment of the requirements for the course. The orientation and exposure to, observation of, and familiarization with the ship engine room, where their future profession will greatly apply, are the objectives of this navigational trip and the basis of the capacity of each individual student, to complete his degree in maritime field of profession as a marine engineer(De Leon, 2000).

At maritime university, specifically John B. Lacson Foundation Maritime University-Molo, Iloilo City, Philippines, the on-the-job training and apprenticeship program had been launched in line with their philosophy and objectives to produce better quality midshipmen by exposing these potential officers to actual experience on board vessel in the domestic and or foreign trade (JBLF Manual 1999).

Specially, the navigational trip has an equivalent approach to apprenticeship, which is conducted, on the sea going vessel. The navigational trip is a requirement for marine engineering students on their third year. It is being guided by qualified instructors for them to be more acquainted with and have a thorough knowledge of the engine room set-up.

The apprenticeship is a requirement after completing the basic courses and after which one can be qualified as graduate from the bachelors degree in Marine Engineering. A two-year apprenticeship onboard the vessel is required of each student. The school closely monitors this before they are issued a special order as basis of their completion of the bachelor's degree.

The factors involved in this study are the orientation and exposure to, observation of, and familiarization with the engine room, which will yield feelings of satisfaction or no satisfaction. They are to be the under lying factors in this study, because they are the basis for yielding a qualified potential officer and an excellent graduate of a Marine Engineering School. Also, this study will ascertain factors that influence the student performance and navigational trip. Finally, this study will ascertain whether or not there is a relationship between navigational trip and the performance of students in Auxiliary Machinery 2 subject.

As marine engineering students of maritime university in Iloilo City, have strived hard to meet the standards required for international and national (local) employment. Also, the marine engineering students tried hard that the name of this prestigious institution (JBLFMU-Molo) will not be tarnished because of the mediocre performance as future seafarers. Also, the school must provide the marine engineering students the opportunity to have hands-on and on-the-job training programs so that they can equip themselves in the cognitive and skill-based training necessary for the future employment as seafarers.

This study was intended to identify also the correlation between academic performance in the Auxiliary Machinery 2 subject and navigational trip. In order to understand the present study, the conceptual framework is shown in Figure. 1.

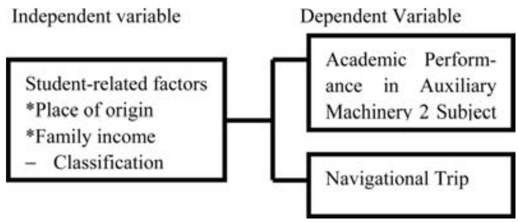

Figure 1. Correlation between navigational trip and performance in Auxiliary Machinery 2 subject.

2 STATEMENT OF THE PROBLEM

The present study aimed to ascertain the level of academic performance in auxiliary machinery 2 subject and navigational trip among marine engineering students and the relationship of the two variables. Specifically this study sought to answer the following questions:

1. What is the level of academic performance in Auxiliary Machinery 2 among marine engineering students when taken as an entire group and when classified according to different categories?
2. What is the level of Navigational Trip among marine engineering students as an entire group and classified according to different categories?
3. Is there a significant relationship between academic performance in auxiliary machinery 2 subject and navigational trip among marine engineering students?

3 SIGNIFICANCE OF THE STUDY

Administration. They will be given insights in the perception of students in the gains obtained by the third year marine engineering students who undergone navigational trip.

By this, it could serve as a basis in improving the navigational trip program.

Students. They could be able to appreciate the purpose of holding navigational trip.

4 RESEARCH DESIGN

The researchers employed the quantitative research design in this investigation. Descriptive research according to Gay (1992), involves collecting data in order to test hypothesis, to test answer question concerning the current status of the subject under study.

The independent variable of this study was the student-related factors such as classification, type of residence, and monthly family income. While dependent variables were the students' performance in Auxiliary Machinery 2 subject and navigational trip.

Table 1. Distribution of participants.

Category	f	%
A. Entire group	99	100
B. Family income		
P12,001 & below	72	72
P12,001 –30,000	24	24
P30,001 and above	3	3
C. Type of residence		
Rural	78	78
Urban	22	22
D. Classification		
Class A	33	33
Class B	33	33
Class C	33	33

5 THE PARTICIPANTS

The participants were the ninety nine (99) marine engineering students of the regular classes randomly selected for the purpose of this study.

The distribution of participants is shown in Table 1.

6 DATA-GATHERING INSTRUMENT AND STATISTICAL TOOLS

To come up with the data needed for this study, the questionnaire – checklist on "Navigational trip" was developed by the researchers. Frequency counts was used to describe the profile of the respondents in terms of type of residence, family income and classification, mean was employed to describe the navigational trip and students' performance as perceived by the second year marine engineering students at maritime university, specifically John B. Lacson Foundation Maritime University-Molo, Iloilo City, Philippines. To determine the correlation between academic performance in auxiliary machinery 2 subject and navigational trip among the marine engineering students, Pearson r Coefficient of Correlation was used.

7 RESULTS OF THE STUDY

The results revealed that:

As an entire group, the level of academic performance was "excellent" ($M = 4.32$) among marine engineering students of JBLFMU-Molo, Iloilo City, Philippines.

Marine engineering students who stayed or resied in rural and urban areas had "very good" and "excellent" academic performance ($M = 4.12$; $M = 4.50$) in Auxiliary Machinery 2 respectively. The respondents' academic performance was "excellent" ($M = 4.27$; $M = 4.28$) whose family income belong to high and low income groups and "very good" for middle income group ($M = 4.13$). In terms of classification,

Table 2. Level of the academic performance in Auxiliary Machine 2 subject among Marine Engineering students.

Category	M	Description
A. Entire group	4.32	Excellent
B. Type of residence		
Rural	4.12	Very good
Urban	4.50	Excellent
C. Family income		
P12,000 and below	4.27	Excellent
P12,001 – P30,000	4.13	Very good
P30,001 and above	4.28	Excellent
D. Classification		
Class A	4.47	Excellent
Class B	4.61	Excellent
Class C	3.45	Very good

Legend:
4.21-5.00 – Excellent
3.41-4.20 – Very good
2.61-3.40 – Good
1.81-2.60 – Fair
1.00-1.80 – Poor

Table 3. Level of navigational trip among Marine Engineering students of JBLFMU-Molo.

Category	M	Description
A. Entire group	4.02	Moderately satisfactory
B. Type of residence		
Rural	3.34	Satisfactory
Urban	4.15	Moderately satisfactory
C. Family income		
P12,000 and below	4.18	Moderately satisfactory
P12,001 – P30,000	3.22	Satisfactory
P30,001 and above	4.12	Moderately satisfactory
D. Classification		
Class A	4.16	Moderately satisfactory
Class B	4.13	Moderately satisfactory
Class C	3.32	Satisfactory

Legend:
4.21-5.00 – Highly satisfactory
3.41-4.20 – Moderately satisfactory
2.61-3.40 – Satisfactory
1.81-2.60 – Unsatisfactory
1.00-1.80 – Very unsatisfactory

the marine engineering students posted an "excellent" for class A and B (M = 4.47; M = 4.61) and "very good" for Class C ((M = 3.45) on their academic performance in Auxiliary Machinery 2 subject.

As an entire group, the navigational trip was "moderately satisfactory"(M = 4.02) among marine engineering students. Marine engineering students who stayed or resided in rural and urban areas found "satisfactory" and "moderately satisfactory" the navigational trip (M = 3.34; M = 4.15) respectively. The respondents' navigational trip was "moderately satisfactory" those family income belong to high and low income groups ((M = 4.18; M = 4.12) and "satisfactory" for middle income group (M = 3.22). In terms of classification, the students posted a "moderately satisfactory" for class A and B ((M = 4.16; M = 4.13) and "satisfactory" for Class C ((M = 3.32) on navigational trip.

The correlation between navigational trip and auxiliary machinery 2 subject of the present study revealed a significant correlation.

Again, the result of correlation between auxiliary machinery 2 subject and navigational trip revealed a positive and significant correlation employing Pearson's r ($r = .735$, $p < .05$).

8 CONCLUSIONS

The level of navigational trip was perceived to be "very satisfactory" when taken as an entire group. This means that navigational trip is necessary among marine engineering students in developing their personal and technical skills, as well as to social relationships. This finding was in agreement in the study of Casco (2003) stating that attending navigational trip, the students are exposed to actual sea experience.

Table 4. Correlation between navigation trip and academic performance in Auxiliary Machinery 2.

	Academic Performance Auxiliary Machinery 2	
Variable	r	r-prob
Navigational Trip	.735*	.024

*$p < 0.5$

Marine engineering students were observed to have developed the sense of cooperation with co-seafarers, learned to follow the command of their superiors and learned to apply theories in their classes to actual situation. That is one of the reasons that the result revealed a significant correlation between academic performance in Auxiliary Machinery 2 subject and navigational trip among marine engineering students.

9 IMPLICATIONS FOR THEORY AND PRACTICE

Navigational trip gives the marine engineering students a chance to meet and talk with people in the field that could provide them with information about their profession (JBLF SPS Manual).

The findings of this study are supported by the objectives formulated by maritime university, specifically John B. Lacson Foundation-Maritime University-Molo, Iloilo City, Philippines regarding the navigational trip or On-the-job Training (OJT) emphasizing that actual sea experience and exposure to the field of marine engineering is productive in the development of students.

10 RECOMMENDATIONS

Based on the findings of this study, the researchers arrived at the following recommendations:

1. Navigational trip program should be conducted effectively to ensure that students may develop their personal, technical and also social skills especially those marine engineering students belong to Class C category.
2. Personnel in-charge of the program should see to it that the implementation of the navigational trip program will be strictly observed so that the students will be oriented not only as simply an excursion or vacation.
3. Further studies be conducted to ascertain the effect of navigational trip in the teaching-learning process of marine engineering students at maritime university, specifically JBLFMU-Molo, Iloilo City, Philippines.

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16.3 Higher performance in maritime education through better trained Lecturers

R. Hanzu-Pazara & P. Arsenie
Constanta Maritime University, Constanta, Romania

L. Hanzu-Pazara
"Ovidius" University, Constanta, Romania

ABSTRACT: The necessity to have good trained officer's onboard ships today comes in complete accordance with the present development of the shipping industry, materialized through presence of high technology and computerized equipment. This is not just an IMO request, but is an imperative in order to have safer seas and oceans and a cleaner marine environment.

The training level of present and future officers is directly connected with the level of training and knowledge of trainers and teachers. For this reason we consider as compulsory to reach higher performance for the personnel involved in maritime education, especially in the academic field.

In this way, in the present, Constanta Maritime University is developing a project dedicated to initial and continuous training of younger lecturers, who are for the first time in contact with the maritime educational system. Also, this project have parts dedicated to experienced lecturers with many years in the system, targeting the goal of maintaining the level of knowledge already acquired, and bringing new training procedures and techniques in accordance with the present necessity.

In the present paper we will describe the concept of this project, its principal goals and courses developed inside in order to have better trained trainers from their beginning activity.

1 INTRODUCTION

Interaction between human and oceans are more intensive in the present than the past. Oceans and seas make possible connections between world states, with a great value for economical changes and transport activities. The maritime transport takes the first place if we consider the transported quantity over the world. The development of the maritime transportation and its connected activities imposed the necessity of having more trained people involved in operation, able to act in different situation. This ability can not be considered as a native one, and it must be developed through specific training.

For this reason the training process, especially related knowledge and skills in operation, safety and security fields, must be highly qualified. Taking into account the fact that this training is covered in many cases through academic studies, is compulsory to have an academic staff able to assure a training process at high level. This training includes both theoretical knowledge and also practical skills. In order to persuade the trainees about necessity to be better trained for an expandable work market and in continuous development, is necessary to prove, as teacher or trainer, that you have in possession the latest knowledge and equipment.

This ability is a difficult task for the younger teachers, coming directly from the school, with a good theoretical luggage, but with gaps in the practical area. On the other side, in the maritime academic system is really difficult to bring people with a wide practical experience in the background, due to different knowledge gain between onboard and on table.

In order to cover the missing experience of a longer practice on sea, our university developed a project dedicated to initial and continuous training of the younger lecturers, and not only, to make easier reaching a teacher position and to fill up the gas related to new technologies used in the training process.

2 THE MARITIME INDUSTRY AND MARITIME ACADEMIC

2.1 *The maritime industry*

From the beginning of times, people have been attracted by the sea, by the possibilities to interact with other peoples, especially for trade and also for social and cultural development. The main way of transport used in trading relations is represented by the maritime transport, first because of the quantity transported, second due to the price. Once economical relations got wider, the maritime industry had to adjust the capacity to satisfy these requests. The growth of the ships capacities becomes obvious starting from the 70's and continues during present time. This development requests increasing quality of operability, bringing onboard the ship the newest technology and people able to work in these new conditions. The improvement of technology and this presence of high technology onboard ships, is changing the concept of classical sea transport and in consequence requires people trained for this.

Not only one part of maritime industry has changed, the ships, also they have changed the connecting activities during last decades. So, the port operations, shipping company activities and others have suffered changes and requested personnel trained for the new conditions.

Even if technology evolved, the basic activities and the operation of equipments are still human duties. The maritime industry is based on human element and, in this way, the necessity to invest in human factor must be a high priority. To have personnel qualified according to technological standards, is a request that can prove difficult if it doesn't exist adequate background training. A solution can be represented by the training onboard ships, directly on the working elements, but can have the inconvenience of missing knowledge's in case of changes.

Also, the technological changes impose continuous updating of older employees, people familiarized with the previous equipments, which have also gaps into theoretical field related, not only into practical experience. Here, the difficulty consists in the age of the employees, their position facing new technology and, not in the end, the ability of achieving sufficient knowledge to assure a good and safety operability.

With the younger personnel, problems related to accessibility to the new are less; they are living in the technological era and have more resources to comply these onboard ships. Also, if they are correctly trained and are open to latest techniques, they will be able to help their older colleagues in achieving knowledge and skills in operating computerized equipments.

Now, after the ships have been modernized, armed with computerized equipments and high technology in order to provide a safety operation, to increase protection of the human life and of the environment, is the time to improve people capabilities.

These requests can be solved through a better learning and a training period before taking responsibilities onboard. During this period, they must be teach about new ship types, their characteristic operations, the differences between different types, about technology already onboard, configuration and operation, situations which can be met during a voyage, organizing and managing of onboard activities and duties and about everything is necessary to provide a rightful and safe activity.

This is in our duties, as academic staff, to satisfy the present requests and necessities of the maritime industry, to provide people, both deck and engine officers able to work and react in different conditions and situations encountered during activity.

2.2 *Maritime academic role in maritime industry*

As stated before the maritime universities have important duties and responsibilities near the maritime activities. The maritime academics do not have only one role, that of training, they are also formative institutions for maritime officers, including personality modeling and developing a responsible behavior of their actions. Is in human nature to borrow from other people's personalities, from teachers or trainers in this case. Being examples, the teachers have to show only the better part of their personality, oriented on their professional knowledge and skills and to correct the intention of the trainees to become a copy, to help them develop their own personality, based on a model.

For this, is important for teachers to use in the training process their experience in working with people, to complete theoretical knowledge with practical examples and advices, based, if is possible, on own experience on sea, if not, on studied cases. To do these is necessary that teachers to possess an adequate level of training and to have knowledge's from domains complementary to their teaching area.

Doing this, trainers training from the beginning of their academic carrier, is a more acceptable situation, because of fresh theoretical knowledge acquired during studies period. It will be necessary just to introduce them in the teaching techniques, to use different teaching materials and to teach them to target the maximal goal, in order to have at the end good prepared people for their future professional life. For teachers involved in training process from many years, the scope is to keep them in line with technological development, to convince them to pass from classical teaching methods to the new ones, to include in their activity the use of computerized and simulated application, also distant open learning and e-learning concepts.

Starting from these ideas, Constanta Maritime University developed a project addressed mainly to the younger lecturers, but also to all lecturers; inside of it, it has been created a curricula of courses based on actual requests for training level of trainers. It have been covered knowledge and skills related by using the training technologies, as simulators, the development of an e-learning course, management of knowledge, class courses curricula developments, various pedagogical methods, how to create good relations with your trainees and other objectives used for becoming a better trainer or for updating with technical advance.

3 THE "MARCON" PROJECT

3.1 *The international context of the project*

The "MARCON" (Improvement of Maritime Lecturers Competencies) project is based on politics and strategies fated to support the European maritime academic system position into the worldwide context.

The project is develop according with Lisbon European strategies with scope to make from European Union a dynamic and competitive community with an economy based on knowledge, with much and better working places, increasing investment in education and research activities. For these, the Commission in relation with member states and universities will put in practice concrete actions related to continue professional formation in educational field.

Starting from 2001, once the eEurope plan has launch, through e-Learning initiative, the communication and computerized technology became an important element of educational system.

All of these strategies opened new possibilities for universities and their staff, as increasing of quality in academic level, professional promotion to easement the economical grow and develop of society based on knowledge.

European Commission considers the maritime transport development as an important element in general economical growing. In this context, the maritime training system is the part which offer qualified work force on European market.

Also International Maritime Organization put accent on the level of training in the maritime educational system. With the latest intentions of changing of the levels of training, in order to improve the STCW Convention, has appear as necessary to be known the actual equipments and technologies meet onboard ships. These requirements need people trained and familiarized with equipments, able to train others.

3.2 *Project objectives*

The general objective of the "MARCON" project is represented by multidisciplinary researches concerning initial and continuous formative of the lecturers from maritime universities and providing of advancement programs according with the maritime industry requirements.

Achieving of this objective will lead to increasing of maritime lecturers competencies and also will make attractive for graduates to come in the system.

The results of this project, the initial and continue formative courses, are addressed to all debutants lecturers and also to older lecturers.

According with equal chances concept, can be observed, that in an activity domain dominated by the male, attendance of females is not treat as abnormality. As long women are presented onboard ships, in many cases in managerial position, their presence in the maritime universities is not treated with skepticism.

The development of the maritime industry imposes the implementation of a framework for providing of advancing programs due to continue changing of this activity domain.

Beside general objective of the project, the specifically objectives are:

1 Increasing of lecturers competencies through promotion of knowledge's and technologies in the academic maritime field.
2 Creation of a development, update and on-line management framework for initial and continue formative of the human resources.
3 Realizing of studies and analyze to define formative programs dedicated and an optimum correlation of these with maritime industry necessities.
4 Increasing of access and participation of lecturers to formative programs and to obtain a double qualification.
5 Encouraging of lecturers to maintain a high qualification level through participation at specialized courses.
6 Introduction of carrier advancing opportunities for younger lecturers.
7 Elaboration of 6 pilot courses and analyze of the feedback.
8 Verifying of the process and teaching activities through initial and continue formative programs in scope of improvement of TIC using level.

All these objectives are based on premise than continue learning is the main condition for restructuring and development of educational and formative systems, for assuring of decisive competencies during life and to realize the coherency between persons involved in maritime academic system.

A high level of qualification has to be guaranteed by the training institutions through modular and flexible educational structures, completed with high standard personnel.

The project square up many horizontal objectives as durable development, innovation needs and transnational approach.

Durable development has as scope the give up of traditional methods for lecturers formative. Will be followed the alignment to actual and future requirements of the international maritime market, the expected result being represented by a next generation of competitive seagoing officers. The formative objectives will be not state just in theory, it will be extend to objectives focused on knowledge, action, cohabitation, personal and social innovation. In this scope will be taken in consideration economical aspects, problems regarding environment protection, right manage of human resources, all of these resulting in promotion of a durable global development.

The transnational approach of the project is give it by the maritime sector characteristics, an international one and due to teaching act results, the graduates, who will work onboard ships under different nations flags.

This project tries to involve maritime lecturers in international maritime transport framework, to put them in direct contact with the end users of their work, the companies from maritime industries and to know exactly their needs. The international maritime companies are the necessary source of information's regarding worldwide requests for employ of maritime personnel.

Collaboration with partners from maritime field, as project objective, will be found on communication and information changes to identify and implement of adequate modalities to increase the number of work places and to optimize these.

After completed realization of this objective has as results the extension of integration opportunities for future Romanian maritime officers in the international market. For this reason will be looking for solutions to cast away the impediments and to have an objective and equal appreciation.

With these desiderates the transnational and interregional approach will have as scope achieving of a common denominator between national and international requests in maritime transport, able to offer to the future officers the chance to integrate without problems in national, also international work market.

3.3 *The target group*

As is stated in the project name and objectives, the target group is represented by the maritime lecturers, mainly younger lecturers, beginners in the maritime academic. In this category we are including all lecturers, staff of the university, with ages under 35 years old.

Also, older lecturers, are included in the target group of the project, especially in continue formative part.

The attendance to the project courses can be made at the beginning of activity in the maritime academic or after a time, but to not exceed 35 years old, for the initial formative part. Better solution will be to attendance in the first year of the lecturer carrier, when knowledge's received during classes is fresh and capacity to catch new knowledge is higher.

According with this criteria's, in the present, in Constanta Maritime University, the teaching staff on age levels is formed by:

- under 35 years: 22 persons, with positions as assistant professor and lecturer;
- between 35 to 40 years old: 7 persons, with positions as assistant professor, lecturers and associate professor;
- 40 years old and after: 51 persons, with position as lecturer, associate professor and professor.

This statistic show that 40 percent of the present teaching staff of the university is mark as principal target group, able to pass through all steps of the formative program. In this statistic we take in consideration as target on younger lecturers group staff with ages between 35 to 40 years considering that these persons are lecturers with experience on sea, who start their carrier onboard ship's at finishing of study period and after they has become teachers or trainers.

3.4 *Project development*

Initial and continue formative activities for academic staff supposed training in modern teaching techniques, IT domain, simulation applications and in human resources management.

In this direction will be create courses for lecturers, with topics as "Teaching curricula development", "Using of simulation techniques during training process", "Advanced concepts in virtual learning method", "Human resources management in maritime academic", "Maritime academic system development in knowledge management context", "Use of new technologies for research purpose".

These courses has importance in the context of changes in the maritime training system, where in the present it seen the tendencies to pass from theoretical base to theory-practice combination.

"Teaching curricula development" is a course dedicated to familiarize younger lecturers with actual premise requested by maritime field curricula which must contain IMO requirements, as compulsory, also new elements imposed by technical development in the sector. Here are explains modalities of curricula conception, contents, compulsory elements, hours repartition on course and practice, detailing of each course and practice class, trainer and trainee manual elements, use of electronic course development and ways to be delivered to the trainees and other aspects characteristic to each curricula.

The second course developed, is one of the principals, here is describes the actual simulators used in the training process and present in the university possession. There are included simulators of ship handling and navigation, liquid cargo operation, engine operation and crisis situations.

Using of simulators during training process, in a correctly way, can reduce the missing of practice experience of the first years students, they are able to find and be familiarized with the future equipments use in the daily activities on board.

But, for a right use is necessary trainers trained accordingly with scope of training. Is obviously that not all courses need simulation application. But, courses related main activities onboard, as navigation, ship handling, engine operation and cargo operation, depend by the use of simulators during training.

Simulators are new teaching techniques introduced in the process. Once appear these request persons trained for their use. The increased necessity of simulator training asks for more persons able to use it. For this, younger lecturers can be the ideal solution to become simulator trainers and the present project course let them to enter in this area of training and provide knowledge's and practice in simulation.

"Advanced concepts in virtual learning method" is a course created according with the European initiative to improve the education system through a better communication between actors using the advantages offer by the latest technologies, the virtual world. The concept develop in this course is over the present idea of virtual learning, treat as a web based systems, where are posted materials with scope to be downloaded or accessed to be read on the web. The next level in this trend is to create the "virtual teacher", a technology based on interaction between teachers and students on a virtual platform.

To realize this concept is necessary as teacher to know to control the virtual platform, to create modules on this and to keep it up to date with the latest researches in the domain. Interactivity offer possibility to transfer data on interested subjects between teachers and students, help both participant to improve their knowledge's. Here, teachers bring latest researches, as scientific and students can explain the practical experience, own lived and how is possible to accomplished the training process to the real applicability.

Human resources concept in the present project is built on actual strategies in the maritime academic regarding management principals of human elements. The system changes made in the last period affect also the human resources manage, dividing personnel in sectors of activities, as teaching and research areas. Management of resources in teaching area supposed capabilities to organize academic staff on university curricula, to nominate right trained person to according course, to lead activities during course period, including student management on curricula activities.

In the research area, human resources management has main goal the people selection in order to create a good and devoted teams inside projects develop by the university or in collaboration with other educative institutions or with partners from economical field.

Knowledge management represented a creation, maintain and consolidation process of knowledge's inside of an organization, for their use in the most adequate modalities to create values and to generate competitive advantages.

In the new approach, users are producers and knowledge managers, not only consumers, knowledge management being seen as a cyclic process, implicating three correlative activities as creation, integration and dissemination of knowledge's.

Organization flexibility, adaptation capacity, realized through new knowledge's accumulation have to be organization basic characteristic for it evolution.

Knowledge management system is a specific technological system designed for the management of functional bringing in of distributed elements of hardware, software and network compounds in a single functional unit, which sustains knowledge production, acquisition and transfer processes inside one organization. In order to realize this design of knowledge management system in a virtual community is imperative to have a profound understanding of cooperation inside groups or organizations, this implying both artifacts and social conventions. This field consists beside computer sciences (knowledge engineering, distributed artificial intelligence, user interfaces) of some other disciplines: psychology, ergonomics, linguistics, sociology, organizational and management sciences.

At the end, but not in the last, the research activities are very important in lecturer formation and to this the project includes elements to help our younger colleagues to become good researchers. The scientific activities are based on the technological advance and the use of these is essential in many research fields. To be able to initiate and complete a research project suppose to know necessary technologies for it scope. Also are included techniques of research, ways to realize it and how to evaluate results in order to disseminate realizations to the scientific world.

We thing that all these courses will be profitable for persons who come for the first time in contact with the maritime educational system and it processes, helping them to integrate easily and to reach necessary competences to push forward the maritime educational process. For already involved person in the system these can update some aspects related to new approaches, technologies and currents in the maritime academic.

Beside of courses developed by our university in the project, the attendant person's have possibility to participate to courses developed by "Ovidius" University from Constanta, as psycho-pedagogical training for lecturers, World Maritime University, in the Maritime English field or provided by other institutions with duties in training of lecturers competencies.

3.5 *Project complementary*

The project is in direct consonance with the EU policies for maritime university level, expresses through documents as "An Integrated Maritime Policy for the European Union", issued in 2007 and "Green Paper on a future Maritime Policy for the EU", 2006. In this way, the project objectives and activities are elaborated according with the European policies for development of human resources in educational field.

Inside of "MARCON" project objectives can be seen complementary elements with different Leonardo da Vinci projects, as "Developing the competencies of maritime lecturers", which objectives are the identification, analyze and description of the better educational system for teaching personnel in academic level and to consider the formative and informative educational system as professional experience.

Another complementary project is "e-Marine" from Leonardo da Vinci program, axed on creation of two learning centers, real and virtual, dedicate to maritime and port operation training. Inside of this project has been identified and elaborated national standards for seven professions, also has been created two training centers, one virtual, for online training, in maritime field with topics in pollution prevention, increasing of safety of navigation and maritime security, another, as formative center for professions in port operation field.

The "MARCON" project is also in consonance cu the Waterborne Technology Platform program strategy, which objectives are: safety, support and operations efficiency; European maritime industry competitive in order to facilitate increasing and even to change the pattern of actual maritime commerce.

3.6 *Expected results*

Through this project is expected to create competencies for younger maritime lecturers and to improve the competencies of the older lecturer's.

The creation of courses bilingual, Romanian and English, permit other lecturer from national and foreign universities, maritime particular, to take part to these with impact in the number of person's included in the program.

Taking acknowledge of materials contained dedicated to initial and continue formative of maritime lecturers and after to reply with own evaluation, consideration and proposals for improvement of courses will lead to a better correlation of lecturers competencies with maritime industry needs.

4 CONCLUSIONS

The world economy is changing, the maritime industry, as part of it, is changing too and the requirements and necessities are remodeled. To achieve these new challenges is necessary to redesign the training system, the approach principles and people involved.

It will not be easy to change the actual format of maritime training system, mentalities or main topics approach. The transition must be started from the new lecturer's generation and completed with older lecturers through programs for initial and continue formation.

This program's idea has the advantage of mobility, the ability to reach to different generations, to shape up the content according to present requirements and to apply that parallel with the daily activities. Being based on printed and virtual components, it can be accessed by own personnel and by the outside personnel, from other universities or from economic field on interesting fields.

The courses developed in the "MARCON" project are created in the actual trend of maritime education and come to help lecturers to improve their competencies or to create new ones, particularly those related to the use of latest technologies, computerized and simulation procedures.

The competencies and qualification achieved at the end of the teaching processes contained by the project, will make the maritime academic system more attractive, with competent personnel and able to provide to the maritime industry, well trained officers to face the new realities in the field.

The collaboration relationships developed in the project context between the training system and maritime companies will help the rightful deduction of the maritime industry necessities.

According with its structure and concepts, the "MARCON" project can be included in the European project ideas dedicated to the maritime training.

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16.4 Mentoring and the transfer of experiential knowledge in today's merchant fleet

A.L. Le Goubin
London Offshore Consultants, Houston, Texas, USA;
The Nautical Institute, London, UK

ABSTRACT: According to various statistics, the number of marine accidents is rising, and recent increases in the cost of P & I insurance cover provides further evidence that the cost of these accidents is also soaring. This paper establishes that a contributory factor to the increase in accidents is that experiential knowledge (knowledge gained from professional, 'on the job' experiences and reflected upon) is not being passed from senior to junior officers onboard many merchant vessels, in the traditional way that it used to be, by mentoring. Following worldwide research throughout the maritime community by questionnaire, and ethnographic research by the author, the paper will show what is considered to be the most significant lack of knowledge and causation of this lack of knowledge. It will offer some practical suggestions that may break down these barriers and re-establish the flow of experiential knowledge in the multi-national, multi-cultural merchant fleet of today.

1 INTRODUCTION

This paper is primarily based on research recently conducted in partnership with the Nautical Institute and Middlesex University in London. The purpose of my research is to show that a contributory factor to the occurrence of marine accidents, is experiential knowledge (knowledge gained from professional 'on the job' experiences and reflected upon) not being transferred from senior to junior officers onboard modern merchant navy vessels by mentoring; to identify the barriers that are preventing this transfer of knowledge, and then to provide practical suggestions that will help re-establish the flow of knowledge.

In addition, it is my aim to engage the maritime community in a conversation about mentoring and the transfer of experiential knowledge, for although one may not agree with what I am saying, the very act of disagreeing is engaging and is raising the conceptual profile.

During this paper I will briefly discuss:

- What is considered the most significant lack of knowledge at sea today
- The causation of this lack of knowledge, and
- What can be done to re-establish the flow of knowledge.

Throughout this paper you will note un-cited quotations. These are taken directly from my research questionnaires and, whilst due to agreed confidentiality I can't name the responder, I gratefully acknowledge their contribution by engaging in this conversation.

2 DEFINITIONS

In this paper I have used the following definitions:

1. **Candidate** – Anyone receiving experiential knowledge by mentoring.
2. **Experiential Knowledge** – I have defined this as knowledge gained from professional 'on the job' experiences and reflected upon. This knowledge can come from a wide variety of sources or experiences but, in my opinion, it often has the most impact when it comes from an accident, incident or near miss; however it does need to be reflected upon before it can become experiential learning. I will say more on this further into my presentation.
3. **Mentor** – The Oxford English Dictionary describes a Mentor as *'an experienced and trusted adviser'* and sources the origin of the word as *'from the name of Mentor, the adviser of the young Telemachus in Homer's Odyssey'*. In the context of my research I simply define it as the possessor and distributor of experiential knowledge.
4. **Mentoring** – *'Mentoring is a form of knowledge transfer based in part on altruism'* Davenport T. & Prusak L. (1998). I like this definition as, for me, it sums up the unselfish act of knowledge transfer that I myself benefited from in my early days at sea. For the purpose of my research, I have followed this theme and defined mentoring as *'the act of sharing knowledge without a designated reward'*, which definition in itself has caused a certain amount of debate, but I believe it suffices.
5. **Reflection** – *'A thoughtful (in the sense of deliberative) consideration of your experiences, which*

leads you to decide what the experience means to you.' Institute of Work Based Learning. (2008).

3 STATISTICS & SUPPORTING EVIDENCE

According to DNV *'updated figures for 2007 show that losses from navigational accidents within the shipping industry are continuing to increase.'* Soma T. (2007). In this paper I have not incorporated statistical data to support my findings as, lack of experiential knowledge is not generally cited as a contributory root cause of accidents, and therefore its use requires interpretation of accident reports. Instead, I have concentrated on the supporting evidence gained from my research.

4 MOST SIGNIFICANT LACK OF KNOWLEDGE

'Up to 70% of skill is learnt from experience' Trautman S. (2007). It is this maritime skill pool that I believe is not being passed on in the way it used to, by mentoring. With this in mind, and having determined, by questionnaire that insufficient experiential knowledge transfer is considered to be contributing to accidents and incidents, I went on to find what is considered to be the most significant elements contributing to this lack of professional knowledge in today's Merchant Navy.

I must be honest; when I began this research I expected to see the now common themes of, application of collision regulations, standard of certification training and reliance on electronics, to name a few, to be the most prominent response to the question I posed; *'what, in your experience, is the most significant lack of knowledge, that leads to accidents and incidents?'* These expected responses did occur, but not as a significant number, approximately 53% of my responders cited elements that I have collectively grouped as, lack of 'feel', seamanship, intuition, practical knowledge and experience.

But what are these responses actually referring to? *'Whilst much can be taught at college about 'seafaring' it has to be complemented by practical advice from senior personnel, however for the advice to be understood the recipient needs to have (for want of a better word) a 'feel' for seafaring.'*

In the sense the verb 'to feel' is synonymous with 'to experience,' I believe that these responders are articulating the same lack of experiential knowledge that I am referring to in this paper. Let me give you a few more examples:

- *'Ship's officers have ceased to be trained to think and act independently, make decisions based on their own judgments and be accountable for them*
- *Modern seafarers lack a 'feel' for the sea*
- *Inability to act intuitively,* and
- *The inability of modern officers to use their own senses, such as sight and sound and their brains to make decisions.'*

It is not something tangible, nor is it a subject that can be taught in college, although the concept should be addressed and the candidates encouraged to participate in experiential knowledge transfer. It is, as one of my consultant colleagues so sagely puts it *'those gems of wisdom that are passed on during an operation, and that consolidate theoretical knowledge.'*

5 CAUSATION OF THE LACK OF KNOWLEDGE

My next question then is *'what is the causation of this lack of knowledge'?* This question provided much more balanced results and I list the eight top answers:

1. Demands on Masters/Senior Officers time
2. Rapid promotion
3. Multi national / cultural crews
4. Poor training / lack of basic knowledge
5. Attitude / lack of interest
6. Employing anyone who has a ticket
7. Inexperience, and
8. No formal system of training for Senior Officers.

It is the first four responses I want to concentrate on, as they represent approximately 54% of the responses to this question and again, I believe they indicate inadequate experiential knowledge transfer. Taking each in turn, I will discuss how I believe each causation is affecting the transfer of experiential knowledge.

5.1 *Demands on Masters/Senior Officers time*

'Officers are struggling to keep their heads over the growing responsibilities and additional paperwork that has come about due to the additional requirements that have come about in the last decade.'

'Machines have many qualities but common sense isn't one of them. And common sense is lacking in too many seafarers today. The Master has a vital supervisory role of support of the OOW and this role is being neglected by the demands of the "office" on the Master's time.'

I think we can all agree that the Senior Officers onboard today's ships are far busier than they were in say the '80's when I was deep sea. I am at times both shocked and dejected to see the changes that have occurred to the merchant fleet, or more specifically to the mariners onboard today's ships, as they struggle to comply with the everyday requirements of running a modern merchant vessel.

'Lack of time onboard due to fatigue of Officers.' Much has been written about the effects of fatigue including some very good papers – *'Seafarer Fatigue – The Cardiff Research Programme.'* Smith A. et al (2006). There is little doubt that fatigue is a primary cause of accidents but consider for a moment the effect it is having on mentoring; how many of us due to work commitments have time as fathers for our own children? At times during a voyage we are often so tired that we can barely stand up, let alone take time out to

show the third mate again how to do a relatively simple operation. Do it yourself, do it properly, there is always tomorrow to show her again. But that opportunity for knowledge transfer has passed and may not be re-created prior to the incident!

'Masters, Officers are so busy with paperwork that they have no time to observe the crew during their work. If I spend the day on deck when am I going to complete my other jobs, when am I going to sleep and what about STCW?'

This is an interesting comment, although I know that this responder was referring more to hours of rest than when was he going to find the time to be a mentor. So what about STCW and the transfer of experiential knowledge – are there any provisions for the inclusion of this concept? I cannot find any reference that specifically looks at the knowledge sharing that I am referring to – but that does not come as a surprise – however, much is said about training and the minimum standards required for certification. Keep this in mind, as I will mention more about a structured training scheme further into this paper.

5.2 *Rapid promotion*

I have looked at the new foundation degree offered by the UK for training of candidates for their first OOW Certificate and it looks very familiar. It is a three year, five phase course, very similar to the one I embarked on in 1980 although I achieved an HND and now the new officer will achieve an honors degree, in keeping with many of the other maritime training establishments around the world. Further, the UK Maritime Coastguard Agency (MCA) reminds us; *'Master and Officers need to know that the standards expected of the candidate (when competence is reached) is that of a person about to take up the job for which the award is made. Cadets are expected at the end of their training to be competent to start to undertake the job of watchkeeping officer, but they will clearly be lacking in experience.'* MCA (2008). Nothing has changed there! So what is the problem that so many at sea today are referring to? Let us look at a few of the comments I received:

'The manning agents get one or two good reports about someone's performance, and they are fast tracked for promotion – often beyond their capabilities. On the reverse side, I have seen some junior officers demanding promotion after one or two contracts in a particular rank – or threatening to leave – regardless of whether the senior officers believe they are suitable.'

'Lack of time in the long term meaning of the word. Promotions are happening very quickly, people do not have time to experience their knowledge and are being moved one rung up the career ladder.' This is an interesting conceptualization of the learning process where people are not in a rank long enough to '*experience their knowledge'* or perhaps to expand their knowledge base sufficiently with experiential learning to move on to the next rank.

'Many officers today are promoted quickly and as a consequence, lack the foundation of a proper knowledge base'.

'The lack of skilled seafarers has also resulted in a need to employ people who would previously have not been considered as being suitably experienced for a particular rank.'

In answer to this question the respondents who referred to rapid promotion spoke of promotion between ranks and not the length of time that it takes a seafarer to achieve his/her first watchkeeping qualification. Therefore I believe we can assume that initial training is still adequate and that there is further evidence that it is the experiential knowledge traditionally gained between ranks that is missing.

5.3 *Multi national/cultural crews*

This is always a difficult subject to approach and articulate but I believe that it does affect the transfer of experiential knowledge and therefore must be addressed in an ethical manner, supportive of the current regime.

'Much can be traced back to the huge changes that took place in the industry in the early 1980's. Initially the ship owners continued to employ senior officers from traditional maritime nations but employed cheaper junior officers and crew. This resulted in an almost complete break in the flow of knowledge to seafarers who they believed would take their jobs'. This responder goes on to comment '*as things have progressed and the number of experienced officers and crew has diminished, there has been a tendency for crewing agencies to hire a crew of many different nationalities. On individual ships this has sometimes resulted in an almost complete breakdown in the inter-personnel communication.'*

In some ways I am glad to say that the 80's are now well behind us and, in most cases, we have moved on from the attitude described above. I spend a significant amount of my time onboard merchant vessels crewed by a staff of mixed nationalities and, with respect to the difficulties sometimes observed, believe that the problems actually lie far more with a language barrier than with a cultural barrier. As I have undertaken this ethnographic style of research I have also noted that the problems seem to be far more prevalent on vessels with two nationalities rather than those with many. This is, in my opinion, due to the necessity to communicate in a common language on a multi-national crewed ship, whereas with those of just two different nationalities, there is a tendency for each nationality to communicate in their mother tongue and to only converse between the two in a common language when necessary, in essence, de-voiding the vessel of any social communication between the nationalities.

Consider for a moment how much experiential knowledge can be gained by just listening to people talking about a problem, if they are talking in a language you understand, and conversely, how much is lost if they are not.

5.4 *Poor training/lack of basic knowledge*

'Lack of time for informal training – Undermanned ships and over worked staff prevents mentors to take time off their busy schedule and take personal interest in training of juniors.'

From the previous quotes discussed earlier it does not appear to be the initial college training that respondents are referring to, but the training that they receive onboard ships. This, I believe, further evidences the need for all of us to have this conversation and to determine how we are going to share experiential knowledge again.

6 SHARING OF EXPERIENTIAL KNOWLEDGE

So what can we do? How can experiential knowledge be shared in today's merchant fleets? The first thing is to acknowledge that there is a problem and then to ask who is affected? Amongst others, I believe this list would include seafarers, ship owners, managers and charterers, ports and coastal states, flag administrations, underwriters and environmentalists, although not necessarily in that order of precedence. If we are all affected by the problem we should all be involved in searching for a solution.

Time and brevity permit me to only give a few examples of the way we can re-start the flow of information. I would caution that none of these suggestions must be allowed to increase the seafarers' workload. They must be incorporated within the current daily operations as cultural and procedural changes or developments, introduced ethically and quietly at every organisational level.

6.1 *The 10 minute challenge*

This is something I would like everyone to undertake who believe they may be affected by the problem. Sit quietly for just 10 minutes and reflect on what your greatest concerns are regarding lack of knowledge. For myself as a shipmaster, it would start with if any one is looking out of the bridge window, or is there total reliance on technology to keep a look out. Having determined your greatest concern(s), do something about it. In my example, I would talk to my OOW's anecdotally, with examples of clear weather collisions that have happened recently on modern ships and hence why it was important to keep a visual lookout.

I often wonder how many masters who have concerns regarding compliance with their standing orders have taken the time to actually explain to their junior officers the relevance of these instructions and the potential consequences of non-compliance, for both parties. Or is a signature of understanding sufficient because there is no time for more, or perhaps a fear that it could invoke a response? 10 minutes is all it would take.

6.2 *On the job opportunity*

'To gain the maximum amount of synergy from on-the-job experience, cognitive apprenticeships or a transformational learning event requires teacher/facilitator support. Mentoring, guiding, debriefing or teaching is required to maximize the learning opportunities'. Gray I.S. (2007). To achieve this gain I believe we need an adaptive, structured approach to mentoring. Most established shipping companies had a formal system in place ten or twenty years ago and in my early career it was expected that I would understudy the next rank above. This structured system should permeate through all onboard activities and should be utilized through all stages including:

1. Preparation – This could be as large as a Job Safety Analysis (JSA), perhaps a 'toolbox' talk or quite simply just the master, mate or chief engineer taking a couple of minutes to explain what is expected to happen.
2. Execution – While the job or task is underway the mentor should try and point out important/interesting moments and facts and explain them to candidates or better still, let them undertake the task under supervision.
3. De-briefing – After the job or task has been completed, time should be allowed for questions, comments or opinion.

One can imagine the difference this might make to a keen young officer on the bridge who is used to staying in the chart room plotting positions by GPS, when approaching a port or anchorage and is allowed to con the vessel under supervision through the above tasked stages. Even now, I still remember the pride I felt when as third mate; I was allowed, under the master's supervision, to keep the con of a large roro/container vessel as we transited a busy Dover Strait.

I believe that everyone should be routinely training his or her successor. Even on small tasks not requiring formal preparation, every opportunity should be taken to pass on experiential knowledge. If this ethos is followed it should soon become embedded within the culture of the vessel with a resultant improvement in operational standards.

6.3 *External learning facility*

With access to the internet now available to ships it is possible for companies to build a website that gives the mariner real time information on a variety of subjects perhaps relating to vessels within the company, ports visited, cargos carried etc. This is a good way of sharing information within the company and of transferring experiential knowledge remotely. Some companies have taken this further and employ knowledge brokers to facilitate this, but it does not need to be that elaborate. I know of one company that used to have a radio conference call with all their vessels each morning; what a great way of transferring experiential knowledge informally. This concept could also be developed at institution level with access to online mentors. I know from my research that there are many professional, experienced people willing to share their knowledge if we can just facilitate the transfer.

'*Onboard a more structured approach may be necessary – juniors setting down their questions, comments and areas of bewilderment at the actions taken, in an electronic format which could then either be passed on to the senior officers on board or to specific mentors elsewhere. The second option provides some anonymity for the questioner but the first option could/should elicit a response from the senior officer involved in the situation in question.*' I have recently seen a similar concept in place for safety issues. When a potentially unsafe act or occurrence takes place it is dealt with immediately and then a card is filled in detailing the instance. This card is reviewed at the next daily management meeting and any required action taken. The card becomes part of a closed loop system ensuring feedback. Perhaps this style of approach could be used to gain experiential knowledge from an action, when 'the heat of the moment' has passed.

6.4 *Distribution of accident investigations*

I think that it is safe to say that we all like to read a good accident report. I know that when *'Seaways'* arrives each month the MARS reports are usually where I start reading and, as I said right at the beginning of this paper *(experiential) knowledge can come from a wide variety of sources or experiences but, in my opinion, it often has the most impact when it comes from an accident, incident or near miss; however it does need to be reflected upon before it can become experiential learning*.' Many countries produce excellent reports but how many of them actually get to ships where they can be read and reflected upon by the seafarers? One suggestion, which came from one of my consultant colleagues, is to include a newsletter with lessons learned from incidents and accidents in the weekly Notice to Mariners that is sent to every vessel. Not only would the seafarers be able to read this but also it would provide an excellent source of discussion between mentors and candidates. Just recently, IMO has adopted the code to make marine accident investigations by Flag/Coastal States mandatory and these reports will be made available to the industry, so this is an ideal opportunity to ensure that they reach as wide a readership as possible.

In this context, thought must also be given to producing these reports in different languages as I believe so much value is lost if they are only in English. What use is an accident report highlighting the dangers of (say) operating a winch if the winch operator only speaks Chinese? Here, I believe P & I Clubs could play a significant role and mutually benefit, by helping to ensure that the experiential knowledge is transferred to their member's staff in a language they can understand.

6.5 *Structured training scheme*

From my research to date I can find little indication that officers gaining their first certificate of competency are any less trained or experienced than they used to be, in fact in some fields such as the use of electronics they are very often experts! It is the next step that is causing concern as the officer progresses through the ranks. For those seafarers aspiring to, or recently having taken up command, The Nautical Institute Command Diploma Scheme provides an open learning scheme based on the publication *'The Nautical Institute on Command'* with the diploma awarded to those who successfully complete *inter alia* all the relevant tasks in a log book. But what about those officers who are between their first and last certificate, what is there for them to ensure they are gaining sufficient knowledge?

There are schemes available for this and I am aware of at least two companies that incorporate them into their training and career development programmes but, in my experience, this is not common. I recommend that we develop and adopt a universal, formalized system of continuous professional development through the ranks – possibly by extending the "Cadet Record Book" system – this is a task book system – all the way up to chief officer/2nd engineer where it should meet up with the NI scheme. The successful completion of the training programme would then become pre-requisite to the promotion of the officer.

6.6 *Increase in staff*

We have already determined that fatigue is a serious issue onboard of merchant vessels and an undisputed cause of accidents and incidents. I am also a realist and realize that most ship owners will not increase the staffing levels onboard ships unless forced to by legislation. I would urge the responsible administrations to re-visit the issue of safe manning certificates in the context of not only operating the ship safely but also ensuring that the operators' workload is manageable, leaving sufficient time for other activities such as mentoring. Consider for a moment the number of ships in your region that have just two watch keeping officers, what chance is there for one to understudy the other when they are working 6 on and (theoretically) 6 off?

In this context I am pleased to report that some ship owners have considered this and provided an extra officer onboard their vessels to assist with the workload. On one tanker I was aboard recently the master had a young, newly qualified third mate to act as his secretary. This officer was also able to relieve another officer as necessary on the bridge or on deck. The system worked admirably and what wonderful experiential knowledge that young officer was gaining in preparation for when he became Master.

Another suggestion comes from Rik F. van Hemmen in his paper *'The Need for Additional Human Factors Considerations in Ship Operations'* where he suggests that an additional officer be carried as an environmental officer. This additional seafarer would be a chief officer or second engineer nearing promotion and he/she would deal with all the environmental requirements of the vessel whilst understudying the master or chief engineer. I believe that this position would also lend itself well to the concept of mentoring and the transfer of experiential knowledge.

7 CONCLUSIONS

'The fundamentals of seafaring (for deck officers in particular) have not changed over time. To put it simply – to get from A to B without hitting anything, running aground or sinking! For various reasons it appears that many do not understand the basics now at sea and that this lack of understanding is not caused only by a lack of training.'

There is no doubt in my mind that the loss of the transfer of experiential knowledge by mentoring is a problem within today's merchant fleet. My research provides evidence, but I have also seen it with my own eyes, particularly over the last ten years, as a pilot and now as a marine consultant. It is not a 'headline' problem like fatigue and to the best of my knowledge has yet to be cited during a root cause analysis. But it exists and it needs to be addressed.

Is it too late? It certainly is a challenge, especially when it is the most senior officers that lack the experiential knowledge. But on the plus side it is a problem that can be solved, where anyone can instigate change, what ever their position. I respectfully challenge everyone to engage in this conversation, to reflect on the vast amount of knowledge that you have and to take a few minutes out of your busy schedules to pass a piece of it on. It does not have to be much, but it may just be that *'gem of wisdom'* that makes the difference in somebody's life.

Consider also the experiences that you have had in your life to date, some are good and some are bad, but the knowledge that comes from those experiences can only ever be good. I personally believe that, as masters of our various trades, we have a traditional duty to pass on our knowledge through mentoring (or whatever you want to call it) and to put something back into our community of practice that has given us so much.

For, whilst this is but '*a drop in the ocean – oceans are made of drops.'*

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

16.5 Stakeholder satisfaction: Research evaluation of marine engineering cadets' performance at Maritime University, Philippines

R.A. Alimen, M. Gayo, Jr. & V.B. Jaleco
John B. Lacson Foundation Maritime University-Molo, Iloilo City, Philippines

ABSTRACT: This study was conducted to determine the level of stakeholder satisfaction and gather qualitative views and ideas among twenty five (25) company partners – crew managers, personnel managers, training directors of the different shipping companies based in Manila, Philippines. These company-partners are directly involved in the evaluation of performance of marine engineering cadets, specifically of the Marine Engineering Department, John B. Lacson Foundation Maritime University-Molo, Iloilo City. The Performance Prism (PP) Theory was used in this study as theoretical framework to measure stakeholder satisfaction of different company partners. This is an innovative performance measurement and performance management framework of the second generation. Employing quantitative-qualitative method of analyzing the obtained data, the study entailed three phases, namely: (1) survey personally administered by the researchers, (2) the personal interview with the stakeholders, and (3) analysis of the results of the survey using descriptive statistical methods such as the mean, frequency count, and percentage. The information gathered through the interviews was used to validate the results by quantitative data analysis. The data-gathering instrument was the "Stakeholder Satisfaction Survey." Quantitative results revealed that the stakeholder satisfaction level was "moderately high" among marine engineering cadets in terms of communication, professionalism and trustworthiness, communication, discipline, loyalty, consistency of performance, leadership skills, honesty, industry, social responsibility, and initiative to be satisfactory. The different comments, remarks, suggestions, and responses derived from the interviews were used also in the study as qualitative data to enhance and validate the quantitative data. Furthermore, the qualitative views of the respondents were used to suggest some improvements and innovations in the learning process at Marine Engineering Department of Maritime University (JBLFMU-Molo, Iloilo City), Philippines.

1 INTRODUCTION

The stakeholders' satisfaction is considered as the critical investigation of the experiences and views of sets of people who have vested interests in the products and services delivered by an organization (Brooks, Milne, and Johansson, 2002). Furthermore, it was asserted that stakeholder research provides one important set of measures of organizational performance. It encompasses the experiences and perceptions of groups of people who have vested interests in the services delivered by the organization – customers, employees, strategic partners, and special-interest groups. 'Stakeholder satisfaction' is often used to represent the views of these groups, and a common approach to its measurement is to focus on the concept of 'satisfaction' either as an exogenous variable or as a construct based on various attributes of satisfaction. It is in this premise that stakeholders' satisfaction was considered as one of the processes of assessing/feedbacking regarding the extent of skills and competencies demonstrated by the marine engineering cadets of Maritime University (JBLFMU-Molo, Iloilo City), Philippines. Hence, this research was conducted.

2 STATEMENT OF THE PROBLEM

This investigation aimed to determine the level of satisfaction among stakeholders – crew managers, personnel managers, training directors based in the different places of Manila, Philippines.

Specifically, the following questions were advanced:

1. What is the stakeholders' level of satisfaction of the performance of marine engineering cadets employed in the different shipping companies in terms of the following areas:
   a) communication,
   b) professionalism and trustworthiness,
   c) discipline,
   d) loyalty,
   e) consistency of performance,
   f) leadership skills,
   g) honesty,
   h) industry,
   i) social responsibility,
   j) initiative?
2. What suggestions do stakeholders have for performance improvements?

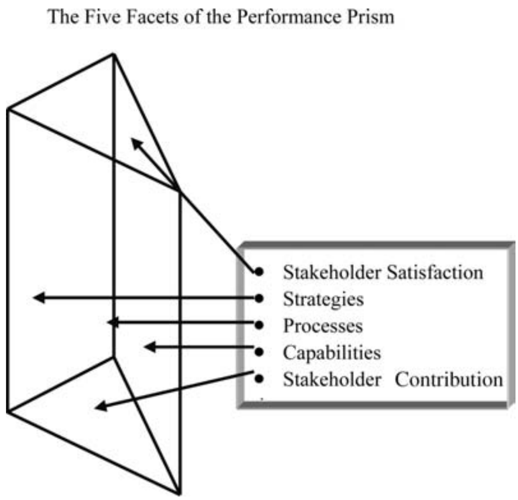

Figure 1. The performance prism (Cranfield University, http://www.12mange.com/methods_performance_prism.html).

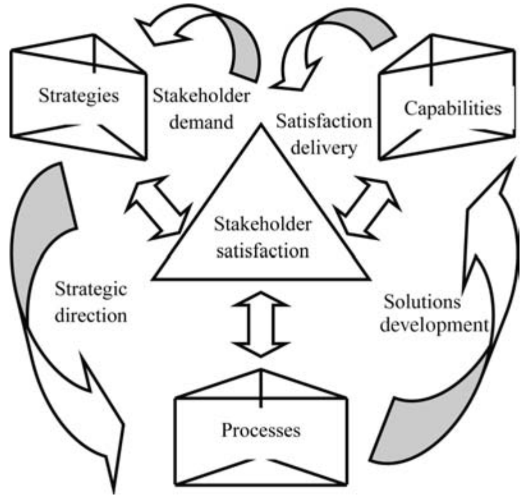

Figure 2. The expanded performance prism (Cranfield University).

3 THEORETICAL AND CONCEPTUAL FRAMEWORKS

The present investigation was anchored on the theory entitled Stakeholder in the Evaluation of Organizational Performance (Chennell, 2000; Bayle, 2001; Brooks, Milne, and Johansson, 2002). It was further anchored on the theory known as the Performance Prism (PP). Cranfield University originated the utilization of the Performance Prism (PP) as an innovative performance measurement and performance management framework of the second generation (http://www.12manage.com/methods_performance_prism.html). As such, reciprocity is practiced by this strategy. In addition, this theoretical framework has five important facets: stakeholder satisfaction, stakeholder contribution, strategies, processes, and capabilities. It must be noted that these five facets are interlinked but may be distinct. Figure 1 below is the "Performance Prism" (PP).

Moreover, the underlying theoretical framework of the workability of the Performance Prism (PP) is the belief that for organizations aspiring to be successful in the long term must have a clear picture of who their stakeholders are and what they want (Brooks, Milne, and Johansson, 2002; Fletcher, Guthrie, Steane, Roos, and Pike, 2003). Consider the expanded model of the Performance Prism in Figure 2. This figure was used leading to the design of conceptual framework of this study.

Figure 2 clearly indicates in essence the interrelationships among the facets in the Performance Prism (PP). The proponents of this framework suggest that for a performance to possess quality, the process should start not from the strategies but from the stakeholders and basically on what they want.

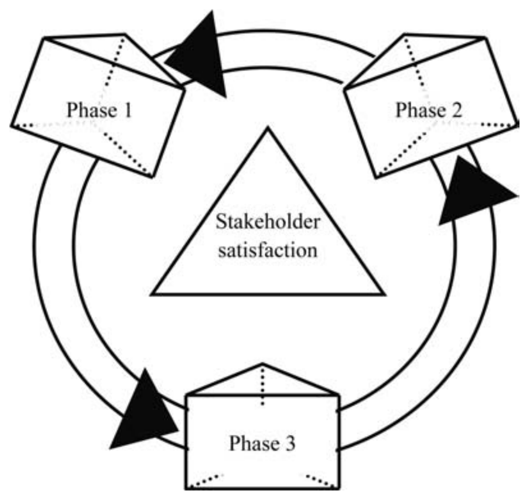

Figure 3. The conceptual framework of the present study.

In a similar manner, the theoretical framework of the Performance Prism (PP) has found its way on how this study has been conceptualized. Figure 3 shows the conceptual framework for this present investigation. The research framework was modified from the Figure 1 Performance Prism (PP) and Figure 2 (The Expanded Performance Prism) as deemed by the researchers with three phases.

The conceptual framework shows the different phases involved in order to determine stakeholder satisfaction. The different phases are further explained in the methodology.

4 METHOD

This study employed the quantitative-qualitative method of analysing the obtained data from the different company-partners of JBLFMU. The three (3) phases were the following:

1 survey personally administered by the researchers, the stakeholders were asked to rate the level of satisfaction using the scales of one to ten on required competencies exhibited by the marine engineering cadets.
2 personal interviews with the stakeholders (crew and personnel managers, training officers, and HRD heads of different company-partners) were conducted, the researchers believed that through the interviews, several suggestions were generated leading to the data that needed in establishing stakeholder satisfaction. In this regard the interview was utilised as one of the qualitative methods to further explain the stakeholders' satisfaction and suggestions. Interviews are "highly appropriate in studying process because depicting process requires detailed description" (Patton, 1990).
3 analysing the results of the survey using descriptive statistical method such as mean, frequency count, and percentage. The mean, frequency, and percentage were used to determine the level of stakeholders' satisfaction and grouping of each category. The information gathered through the interviews was used to validate the results of quantitative data.

5 DATA-GATHERING INSTRUMENT

The data-gathering instrument in this research was the "Stakeholder Satisfaction Survey" which consisted of the following areas of competencies:

a) communication,
b) professionalism and trustworthiness,
c) discipline,
d) loyalty,
e) consistency of performance,
f) leadership skills,
g) honesty,
h) industry,
i) social responsibility,
j) initiative.

These areas were applied to the different levels of seafarers such as: engine ratings (electricians, fitters, oilers, and wipers) and engine cadets. The data-gathering instrument had rating scales of 1 to 10, which were arranged in ascending manner by the researchers. This data-gathering instrument was adopted from the "Stakeholders' Satisfaction Survey Scale" used by the Research Department of JBLFMU-Molo, Iloilo City, Philippines. The instrument was modified by the researchers for the purpose of this study, pilot-tested, and validated by the Members of Research Committee of Marine Engineering Department who were expert in maritime education, research, instrumentation, psychology, and statistics.

The following were the scales and descriptions of the data-gathering instrument used in this study:

Scale	*Description*
8.21–10.0	High
6.41–8.20	Moderately High
4.61–6.40	Neutral
2.81–4.60	Moderately Low
1.00–2.80	Low

6 PROCDEDCURE

The research team determined the level of stakeholder satisfaction. Upon the approval of the administrator of JBLFMU-Molo, Iloilo City, Philippines, the members of the team administered the validated instruments to the respondents of the different shipping companies at Manila, Philippines last summer of 2008. The researchers stayed in Manila during the distribution and gathering of data. The different places of Manila, Philippines that the researchers identified that had the shipping companies were:

1 Taft Avenue, Malate, Manila,
2 Ermita Center, Manila,
3 Roxas Boulevard, Malate, Manila,
4 U.N. Avenue, Ermita, Manila, and
5 Makati City, Metro Manila

These were the venues where these companies situated. The researchers collected the necessary data with the use of the instrument "Stakeholder Satisfaction Survey." The qualitative data were gathered using interview process through open-ended questions.

The researchers went to the different shipping companies and requested the crew managers, personnel managers, training directors, and training officers to determine the level of stakeholder satisfaction by encircling the appropriate scales reflected in the data-gathering instruments. The respondents also listed down the comments and suggestions necessary to improve the education and training of the students while at the university as suggested by Kaplan and Norton (1996). These respondents were subjected also to interviews to gather the qualitative data needed for this study (Patton, 1990; Savage, Nix, Whitehead, and Blair, 1991). After collecting, retrieving, and gathering the accomplished data-gathering instruments, the researchers used appropriate statistical tools to analyze the quantitative data, while the qualitative data were separated and analyzed by determining the common thoughts, ideas, and comments of the respondents towards the goals of stakeholder satisfaction (Mitchell, angle, and Wood, 1997). The ideas, comments, and suggestions of the respondents were grouped and presented in tables as shown in the results' section of this study.

7 RESPONDENTS OF THE STUDY

The respondents of this study were Greek, Japanese, Norwegian, Singaporean, Italian, German, and

American. There were 25 respondents interviewed for this study. The distribution of the respondents was 1 president, 4 general managers, 2 directors, 1 deputy general manager, 1 junior executive assistant, 1 OIC, 7 crewing/manning managers, 1 administrative officer, 3 training managers/officers, 1 operation manager, 2 recruitment managers/officers, 1 cadet program manager.

8 RESULTS

The results of this study were presented into two sections. The first section dealt with the level of stakeholder satisfaction and the next section discussed the suggestions given by the stakeholders in order to improve the performance of marine engineering cadets in terms of knowledge, skills, and attitudes (KSA).

The results of stakeholder satisfaction were 'moderately high' on the performance output of the marine engineering cadets when classified according to different areas. The interpretation and data analysis are based on the scales and descriptions of this study which previously discussed from the data-gathering instrument section. The following are the results of the study:

a) communication skills was "moderately high" with the mean score of 7.1,
b) trustworthiness was "moderately high" with the mean score of 7.1,
c) discipline was "moderately high" with the mean score of 7.2,
d) loyalty was "moderately high" with mean score of 7.3,
e) consistency of performance was "moderately high" with mean score of 7.0 ,
f) leadership skills was "moderately high" with the mean score of 7.0,
g) honesty was "moderately high" with mean score of 7.2,
h) industry was "moderately high" with mean score of 7.3,
i) social responsibility was "moderately high" with mean score of 7.1, and
j) initiative was finally "moderately high" with the mean score of 7.1.

Based on the different areas of competencies, the stakeholders indicated that the graduates employed in their companies performed to their satisfaction. The results employed the scale levels of 1.0 to 11.0 with the descriptions ranging from 'low' to 'high,' the stakeholder satisfaction level is "moderately high."

The "moderately high" level of stakeholder satisfaction indicates the quality of training impacted from the educational institution. The results also imply the realization of the thrust of the University to provide competent and qualified graduates to the global maritime world. Undoubtedly, the University should also consider the availability of alternates or substitutes from other countries like China, India, and Pakistan in case the shipping/manning companies are not well satisfied with the performance of the graduates. The University needs to monitor their competitiveness in order to further improve the stakeholders' level of satisfaction as well as to remain competitive as a major supplier of seafarers in the global maritime market. Interview results were processed and the "moderately high" level of satisfaction was further reinforced by the statements derived from it. Based on the responses derived from the interview questions, the stakeholders' view the cadets' performance of Marine Engineering Department of JBLFMU-Molo, Iloilo City, Philippines was perceived to be satisfactory. Table 1 includes the responses to the interview questions. Note that the responses were edited for the purpose of this study.

Table 1. Answers to the Interview Questions with Reference to Stakeholder Satisfaction.

"JBLFMU-Molo Graduates – as I personally observed and as what people have said – have strong determination, hard working, never surrender for whatever difficulties they were facing onboard."
"They know how to deal and can easily adopt with the attitude of their shipmate or even of foreign nationalities."
"We, at the manning agency appreciate their good performance, they exert more effort in order to survive, and they show that they are capable of the work given to them. JBLFMU-Molo Graduates, Mabuhay."
"Keep up the good work, we are looking forward to visiting JBLFMU-Molo in the future."
"Lastly we are glad to hear about the unstoppable and continuous development in terms of education/trainings as well as the high quality of faculty and staff. We are also exerting our effort to promote JBLFMU-Molo to become well known around the globe."
"The education and training of JBLFMU-Molo graduates who are employed in our company are outstanding, they have the necessary knowledge and skills needed, especially the fresh graduates. They are disciplined, which reflect the kind of training they received in school. We even employ JBLFMU-Molo graduates who are walk-in applicants in our Manpower Development and Cadetship Programs."
"We trust the educational system of JBLFMU-Molo."
"The graduates of JBLFMU-Molo are competent to do the tasks that have been given to them."
"The education and training of JBLFMU-Molo graduates are to be proud of, we are very satisfied with their performance."
"Put to the mind of your men, that education is their wealth. Above all, always praise God."
"More power to the foundation you created"
"Keep up the good work"
"Because had worked for 7 years in Ancora Company, I have met many engineers and cadets. I have to say that the majority of them are satisfactory. They have good characters, willingness to work with others, and hard workers.
Never have a problem with some of them. The cadets that I have met are clever, good educated, and willing to do the work assigned to them."
"JBLFMU graduate has good character, hard worker, willing to learn."

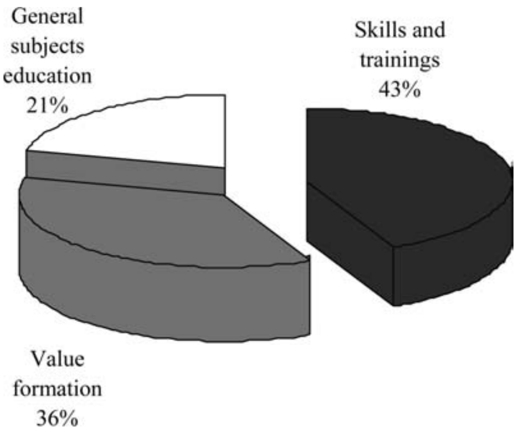

Figure 4. Stakeholder's suggestions for performance improvement.

Based on the responses to the second problem posed by this investigation, "what suggestions do stakeholders have for performance improvements?" Three common suggestions/recommendations emerged: there is a need to enhance the three areas: Value formation, general education courses like Math and English, and Skills and Trainings. Figure 4 shows the results.

This figure shows the three areas that have to be looked into by the institution. From the responses, Skills and Trainings ranked first priority with 43% of the total responses; Value formation ranked second with 36% of the total responses, and General Education subjects with 21% of the total responses. University has to reconsider certain measures and reforms to improve these areas.

The Table 2 reflects the different answers of the marine engineering cadets during the interviews conducted by the researchers. These were presented in this study as qualitative data and used to enhance the quantitative results of this study.

The present study also discovered that, despite stakeholders' satisfaction of the JBLFMU graduates' performance on board, they have advanced some comments, remarks, suggestions, and recommendations on the kind of training that the Marine Engineering Department, JBLFMU-Molo, Iloilo City, Philippines has for the students with special emphasis on the improvement of value formation, enhancement of general education courses, as well as skills and trainings. Note that the interviewees' responses were edited for the purpose of this research but the contexts of the responses were retained.

9 CONCLUSIONS AND RECOMMENDATIONS

The study yielded a favorable level of stakeholder satisfaction of educational performance, although, a more careful look at the suggestions/recommendations from the stakeholders reveal an equally difficult challenge to the institution that has gained a good reputation in the field of seafaring industry. The maritime university has to look into the curriculum and review offerings that turn out better results as far as content and allied courses are concerned. This way, stakeholders' suggestions can be addressed. Research design like this one must be continuously done to elicit issues and queries about an educational performance and thus feed backs can be taken as challenges for more improved educational and institutional reforms. Direct and specific feedback scheme may be done to stimulate administrators and other stakeholders concerned to act, address lapses, and definitely improve institutional output.

Table 2. Answers to the interview questions with reference to stakeholder suggestions on the institution's performance improvement.

"The graduates 'loyalty is observed to be a declining trend. Some have a demanding attitude problem."
"The attitude is not showing respect, (walang po at opo)."
"Although we believe that JBLFMU-Molo strives to give excellent education and training to their graduates, still there are some areas which need concern. Obviously, on top is their poor knowledge in Math. Lately we have been hearing of poor discipline among cadets. There were complaints of arrogance while onboard and even when dealing with office staff during vacation while reporting to the office: Thus, these graduates (1) need to improve on their discipline, (2) ensure clear understanding of the principle of internal combustion engine, (3) improve their mathematics, (4) teach and give exercises on training actual ships piping diagram and electrical schematic diagram, and (5) ensure their clear understanding of theory and principle of separation of fluids."
"Graduates need to study hard and have patience."
"Give all responsibilities to all graduates of JBLFMU-Molo for giving taking licensure exam"
"I have nothing to suggest only some of them need more experience. "Mathematics difficulty needs to be addressed."
"English difficulty must be looked into."

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

16.6 Project PRACNAV for a better on board training curricula

E. Barsan & C. Muntean
Constantza Maritime University, Romania

ABSTRACT: During 2008, Constantza Maritime University has developed a project financed with European funds that aims for an increase in the quality of training and the practical skills of the students that will be working in the maritime industry, by organizing and undergoing on board training stages at higher standards. It is expected that once this objective is achieved, there will be a 40% increase in the chances of employment in the shipping companies for the Romanian students. A coherent, modern application of such a program with fully integrated on board training sessions, would ensure a better chance of employment for our students in the European fleet. If the equality of chances" principle is considered, the increase of theoretical knowledge by acquiring specific practical skills for those students that undergo PRACNAV, for graduates of female gender an increase of up to 60% in their employment chances is expected as maritime officers on board European ships.

1 INTRODUCTION

One of the foremost problems in the maritime transport industry is the lack of qualified well-trained officers particularly in management positions. Such a dangerous situation could increase the number of accidents caused by human error and long-term solutions are yet to be developed.

At Constanta Maritime University, we believe that such a long-term solution is increasing the number of students while maintaining a high standard of training and education. During 2008, a project financed with European funds has been proposed aiming to increase the quality of training and the level of practical skill of the students who will be working in the maritime industry. The main aim of the PRACNAV project is to reorganize the on board training stages of the cadets in order to optimize their professional achievements.

In the years prior to 2006 the students of our university had to surpass great difficulties in order to acquire the 12/6 months period of sea training. In those years one of the most difficult tasks for the deans and rectors was to convince Romanian and foreign ship owners to accept cadets on board their ships. Despite their best efforts only 60–65% of our students found placement, the rest had to resolve this problem the best they could, relying on own personal relations or their luck in order to find an owner willing to embark them as cadets. This situation changed however in 2006, when crewing and shipping companies came to our university asking for cadets. This change in their attitude was a direct consequence of a prognosis confirming the shortage of well-trained officers for the merchant fleet during the next 10 years.

We consider the interest showed by shipping companies in the maritime education process to be most welcomed. If they would involve in all the stages of the educational program rather then act only as passive beneficiaries of the maritime training institutions' outputs, the results could prove most beneficial (Sears D.F. 2003). They have a key role for implementing a good on board training program and for monitoring the way this program runs on board their ships.

According to the provisions of the STCW'95 Convention adopted by the International Maritime Organization, and of the European Maritime Safety Agency (EMSA) that have found an expression in the 2001/25/EC and 2003/103/EC directives regarding the required level of training for a maritime officer, an important aspect of that training is the level of skill acquired by that officer.

Taking into account the above statement, we consider the PRACNAV project as a necessary step, facilitating the transition from the theoretical accumulation of knowledge to an active educational process with a higher level of practical skills that would give to the young Romanian officer a much higher rating on the European labor market.

2 REMOTE MONITORING OF ON BOARD TRAINING STAGES

During the last few years, Constanta Maritime University students returning from their on board training period were asked to fill a questionnaire containing 20 questions. In order to encourage them to answer with the outmost sincerity, we did not ask them to write their names. They were required to write only the name of the vessel/vessels they have been assigned to, the name of the crewing company and/or the owner of that vessel.

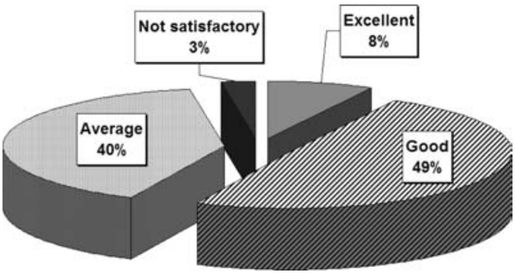

Figure 1. Answers to question: “Give a score for the overall feeling on the on board training period”.

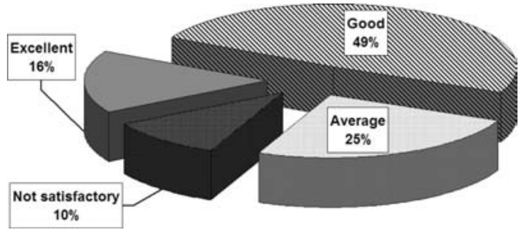

Figure 2. Answers to question: “How would you appreciate the activity of the Designated Training Officer?”.

The most important conclusions of this enquiry were:

- There are great differences between the quality and complexity of the on board training programs performed on board different ships;
- The number of shipping companies that have a modern and systematic on board training system is very low;
- During their on board training period, cadets are not usually guided and monitored by a dedicated STO. They receive guidance from any of the watch officers, including Chief Officer/First Engineer. Any available officer was allowed to undertake assessment and to sign and declare the cadet as proficient in the tasks mentioned in the training record book.
- In most of the cases, the cadets have to learn by themselves, looking and copying the actions and work style of the ship’s officers;
- The quality of life on board is very important for the professional progress of cadets and what they feel in the first 2–3 voyages could determine their options for their future;
- 40% of the students were not very satisfied about their on board experience and it is possible that many of them will not embrace a sea carrier prefer from the start to find o job ashore instead (Fig.1).
- Almost 35% of the voyages undertaken our cadets were not guided and monitored by a dedicated ship training officer (Fig. 2). They had to learn by themselves, looking and copying the actions and work style of the ship’s officers. As the students explained, in most of the cases, they received guidance from any of the watch officers and any available officer was allowed to undertake assessment and to sign and declare the cadet as proficient in the tasks mentioned in the training record book.
- It will be best only to work with shipping companies, without the brokerage of crewing companies, because the university will know from the beginning where the cadets will go and could avoid some unpleasant experience;

The PRACNAV project aim is to improve the quality of professional training and skills level acquired by students, during their on board training time. Because the University has not the possibility to monitor the student’s activity on board ships, we need in the first place to have a very good feedback regarding these periods of training. Until now, our feedback was based only on the sea service qualificative, the grades mentioned in the Training Record Book and the student’s answers to our questionnaire.

Our intention is to provide to the shipping companies a standardized form that should be used to summarize the performances and attitudes of the cadet during the on board stage. This form will increase the shipping companies’ responsibilities for monitoring the cadets’ activity and will allow us to have a better picture of the problems flagged by the owners.

This continuous adaptation to the shipping companies’ requirements would ensure that the students are much better trained and prepared for the realities onboard a ship at graduation.

If this objective is achieved we expect that the chances of Romanian students of being employed on board ships that have U.E. owners would increase with 40%. At this moment students graduating from Romanian Maritime institutions compete directly with graduates from Bulgaria, Ukraine and Poland on the European labor marketplace. The application of this program would give them the edge they need, their experience and skill, enabling them to make a better use of their theoretical knowledge.

The “equality of chances” principle is also considered and due to higher theoretical knowledge and a higher level of practical skills acquired by those students that undergo PRACNAV, the graduates of female gender will have significantly higher chances (an increase of up to 60% in their employment chances is expected) of being employed as maritime/river officers on board European ships (Belcher P et al.

3 NEW TRAINING GUIDELINES

An important aspect of this program is that we have not designed it only for students graduating from Romanian universities. All the materials, the curricula, the training record book, the training handbook for the Company Training Officer (CTO) and for the Ship Training Officer (STO), all the documents and manuals used for individual and group training during sea time, will be prepared in English. A standardized format will be used, in order to facilitate their use by any student of any other maritime university.

According to the STCW Convention the on board training period must be documented in a training record book (TRB)

The importance of this document cannot be disputed. Apart form being an imperative requirement of the STCW Convention it is a very important tool of education especially in the cases of poor management of the on board training. We have found that in the absence of a written plan prioritizing the training steps and stages for the on board training of cadets this document is the only one that gives the STO a clue about what is to be done (Hanzu-Pazara R., et al. 2008).

At this moment, the Romanian Maritime Authority (RMA) publishes a training record book that Constantza Maritime University has the obligation to provide to all of our students. In order to avoid duplication of projects and tasks completion confirmation, CMU agreed with RMA that any TRB issued or used by a shipping company that meets the standards of the Romanian TRB will be accepted as valid.

However, we are not very pleased with the content of this record book, because it does not present the tasks the logical and order established by STCW and the guidelines established by IMO. We have asked our cadets if they had worked with other types, copies of the standard TRB model published by ICS/ISF or other record books issued in accordance with the provisions of other national maritime authorities.

For the purposes of this project we are considering the development and publication of a new TRB, one that satisfies all our needs. We think that marks (scores) must be given to the cadets by the STO for the different tasks that are registered and must be performed by the cadet. If the STO must score the activity of the cadets, he will be more responsible in training and monitoring the on board students.

Also, the long list of task that must be performed confirmed only by done/undone remarks must be replaced with more complex tasks, projects that will combine several competencies that will be demonstrated.

Because for deck cadets, the mandatory training period of 12 month can not be achieved in only one stage, using marks for evaluation of cadet's achievements in different stages will reflect also the professional evolution of the trainee.

The instructors are the second most important target group of this program. For the on board training period our students will find a dedicated trained person that is responsible for their education and development of practical skills.

I order to ensure an equal level of training for all our cadets, no matter the shipping company and the ship itself, a training guide designed for the STO is a must. We assume that are very few companies that have some sort of guidelines or at least recommendations for their officers regarding the mode of undertaking the on board training of young cadets (Barsan E., et al. 2007).

Consequently, in most of the cases the STO is on his own judgment, interest and talent regarding the organization of the on board training for cadets. Some pedagogical skills are needed for all trainers if we want to obtain a positive training result.

During the PRACNAV project we will try to elaborate a concise guide of how the on board training stages must be organized and how the students must be coached, monitored and evaluate.

Any how, the main point of the guideline consist in the prioritizing the on board training objectives, in accordance with the theoretical level of knowledge of the student.

The training materials for PRACNAV instructors (the CTO – Company Training Officer, and the STO – Ship Training Officer) will be distributed within those shipping companies taking part to this program. We will undertake short courses for the CTOs in order to make them more aware about the real potential of our cadets and about the realities of the present MET system achievements and minuses.

All shipping companies are trying to select the best of the students applying for a cadet position. In reality, only 25% of these students can fulfill all the expectation of the owner. The rest of the applicants are students with average or under average level of theoretical training (Barsan E. & Muntean C. 2008). If these students will have the opportunity to participate on a good quality on board training process, they can be "converted" in valuable maritime officers and their interest for the theoretical training will increase also.

If only the top 25–30% of the MET graduates will be employed on board ships, it is obvious that the deficit of officers in the world fleet will be maintained.

4 OTHER PRACNAV PROJECT OBJECTIVES

The specific objectives of PRACNAV project are:

1. The familiarization of students to the reality on board a ship, and to the ways a multicultural and multinational crew member interact with one another.

   The quality of life on board is very important for the professional progress of cadets and what they feel in the first 2–3 voyages could determine their options for their future. We expect that for many of them the shock of being part of a multicultural crew, away from their homes for a long period of time, possibly for the first time, might be an overwhelming experience.

   Although many students are motivated only by the money that they will earn as cadets when they choose a company, an unpleasant experience could mean many will not embrace a sea carrier and will prefer from the start to find o job onshore (Junzhong B., Mingqiang X. 2007).

   This is why a coherent application of this modern program in collaboration with the shipping companies, without the brokerage of crewing companies, would enable our university to monitor the progress of it's students, preventing such disagreeable situations from happening. We consider that this would greatly reduce the number of students that abandon the career of maritime officer.

2. Ensuring that the students can use their theoretical knowledge on board a ship in a practical situation, by using complex simulator training programs that are specific to the maritime transport industry.

   According to the 724/2004/EC directive of EMSA an important characteristics of a future maritime officer is the knowledge and skill with witch he operates modern electronically equipment. This level of proficiency can be achieved by our students during their training with the complex simulators. These training sessions under the supervisor of instructors will help them gain the necessary information, and will allow them to quickly adapt to the ship's equipment particularities before arriving on board a real ship (Barsan E. 2007a).

   Usually training with the help of simulator follows the theoretical curricula of the courses directly related to the seafarer's profession and mentioned in STCW. Due to the limited number of hours that can be allotted to simulator training and taking also into account the higher costs of such a training, the scenario used for simulation are trying to concentrate as much as possible events in a short period of time 9 Raicu G., et al. 2007).

   Consequently, the student is the entire time alert and prepared to respond to the challenges impost by the scenario. A more realistic approach will be tested, meaning that in that pre-sailing training using simulators, we will run scenarios were the main task is to perform the navigation watch in almost routine conditions. Exercise will take minimum 2–2.5 hours, and during that time there will be only one or two events that will require attention and application of the normal watch practice.

   For the skills acquired by students in the simulator room, the exercises/scenarios used for training will be designed in such a way that they can be used by any maritime university, having similar simulating equipment.

3. Engaging in partnership relation with a minimum of 12 European shipping companies that will employ at least 70% of the students that have undergone their on board training on the ships owned by those companies (Barsan E. 2007b).

   We consider the partnership with at least 12 European shipping companies to be a minimal condition for the smooth running of the PRACNAV project. The finality of this project is that our students should become maritime officers with a recognized higher level of skill. Because of this we expect that the companies would want to employ at least part of them. This in turn would lead to competition between students that would only improve their level of proficiency, as they try to prove worthy for employment.

4. To ensure that all students benefit from a on board training on maritime ships, that have European owners, for a period at least 5 months.

   The STCW 95 Convention imposes a period for on board training for all maritime students. With this in mind we must realize the fact that because of the large number of our students not all of them will have the benefit of being cadets on board training on ships with European owners for this whole period.

5. Monitoring the professional career of the graduates for a period of at least 2 years since the moment of their graduation, with the purpose of determining the international companies with the higher percentage of employment for Romanian maritime officers.

   This objective is crucial for determining the effectiveness of this program. What we hope is that major shipping companies will show a great interest in PRACNAV and in the students graduating from our university.

   We hope that the international crisis that will affect also the maritime transport will have a limited impact on the seafarers' employment.

5 CONCLUSIONS

In conclusion the shipping companies are the beneficiaries of the maritime educational process. Those companies that show a real interest in this process demand that within the curricula particular attention should be given to the on board training of students. The PRACNAV project is envisioned to be an modern, integrated system of training, for senior maritime students, that respects all the legal requirements and conventions recognized at European or international level. At the center of this project lies the on board training period, with the participation of shipping companies.

This approach is unique, because it strives to cover all the aspects of a practical training process in it key phases: at the university, and on board a ship. At the same time emphasis is put on feedback, with the aim of ensuring the quality of the training process.

All the documents and manuals used for individual and group training during sea time and manuals, the training handbook for the Company Training Officer (CTO) and for the Ship Training Officer (STO), all will be available for use by other maritime universities in the UE that have a educational program that respects he provisions of the Bologna Convention.

There is a single major concern at this moment regarding the positive implementation of PRACNAV and the tangible results of this project after finalization. The world economic crises seams to affect from the early beginning the shipping industry. We are afraid that in order to reduce costs, owners will lower the number of cadets taken on board and also will decrease the founds for training of their crews.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

16.7 A new tool for evaluating and training of chemical tanker crew: Seafarer evaluation and training software: DEPEDES (SETS)

O. Arslan, O. Gurel & M. Kadioglu
Istanbul Technical University Maritime Faculty, Tuzla, Istanbul, Turkey

ABSTRACT: Shipping industry is growing regularly and regulative bodies of the industry put more emphasis on safety and environmental management of ships and ship management companies. With regard to the shortage of human resource officers, which will be continued by following years according to latest surveys, shipping industry has hard times to employ qualified officers in their fleets. Especially for chemical tanker ships, it is needed more qualified seafarers regarding to the environmental and safety concern of public and industry. Therefore, training of seafarers has become more important then ever before. Training of seafarers in office environment before sea period is as important as training at training institutions and on-the-job training. Therefore, measuring of seafarers' performance and planning of individual training programs for each seafarer has become more important than ever.

In order to develop the quality of seafarer training and consequently maintaining safe and profitable shipping, the factors which are important for evaluating the chemical tanker crew are determined and clustered in hierarchical manner; the weighting of factors for each rank are observed by utilizing Analytic Hierarchy Process (AHP) Method; the trainings which should be given to seafarers related to scores of evaluation factors are determined then the Seafarer Evaluation and Training Software DEPEDES (SETS) is created by utilizing Visual Basic Software. In this study, the content of SETS software is evaluated with details. Consequently, the main aim of this study is to maintain safe chemical tanker shipping by utilizing SETS software.

1 INTRODUCTION

According to the latest surveys, officer shortage will be continued increasingly (BIMCO, 2005). Chemical tankers are complex ships that they are designed to carry many different type and dangerous chemical substances; so this type of ships requires well educated and trained seafarers (Arslan & Er 2008). Especially for chemical tanker ships, it is needed more qualified seafarers regarding to the environmental and safety concern of public and industry. Therefore, training of seafarers has become more important than ever before (Arslan & Turker 2008). Training of seafarers in office environment before sea period is as important as training at training institutions and on-the-job training. Therefore, measuring of seafarers' performance and planning of individual training programs for each seafarer has become more important than ever. In order to develop the quality of seafarer training and consequently maintaining safe and profitable shipping, the factors which are important for evaluating the chemical tanker crew are determined and clustered in hierarchical manner; the weighting of factors for each rank are observed by utilizing Analytic Hierarchy Process (AHP) Method; the trainings which should be given to seafarers related to scores of evaluation factors are determined then the Seafarer Evaluation and Training Software DEPEDES (SETS) is created by utilizing Visual Basic Software. In this study, the content of SETS software is evaluated with details. Consequently, the main aim of this study is to maintain safe chemical tanker shipping by utilizing SETS software.

2 METHODS USED IN THIS STUDY

After the observing of evaluation factors, the evaluation factors are clustered in hierarchical structure and the weighting of factors are calculated by utilizing Analytic Hierarchy Process (AHP) Method.

AHP is a mathematical tool that is developed by Saaty (Saaty, 1980). It is used for analyzing complex decision problems with multiple criteria (Vaidya & Kumar, 2006). Generally it is widely used in several areas such as solving decision problems and strategic planning etc. AHP is based on pair-wise comparisons that enables decision makers to assign a relative priority to each factor. In this study, the pair-wise comparisons among evaluation factors has done by crewing managers and operation managers of a chemical tanker company. Seafarer Evaluation and Training Software (SETS) is created by using Visual Basic Programming Software.

3 SEAFARER EVALUATION

3.1 *Seafarer groups*

Four different seafarer groups are observed for different criteria or weight of criteria. These groups are Senior officer group (Master, Chief Officer, Chief Engineer and Second Engineer); Junior officer group (2nd, 3rd and other deck officers, 3rd, 4th and other engine officers; electrician and other officers), Rating Group (Boatswain, A/B, O/S, deck boy, donkeyman, oiler, wiper, fitter, pump man and other deck and engine department ratings) and Service group (Cook and Steward). 34 evaluation criteria for Senior officer evaluation and 31 criteria for junior officer group, rating group and cook & steward group evaluation observed and the evaluation criteria grouped in four main clusters:

– Professional Knowledge & Skill and Adaptation to Safety Rules
– Professional Behavior
– Leadership and Social Behavior
– Adaptation to Sea and Ship Life

3.2 *Senior officer evaluation criteria*

The Following Evaluation factors are observed for senior officer evaluation:

Professional Knowledge & Skill and Adaptation to Safety Rules group criteria:

– Profession knowledge (General)
– Profession experience
– English level
– Understanding talent
– Work planning
– Working carefulness
– Knowledge of equipment
– Evaluation and timing of requisitions
– ISM knowledge and adaptation
– Operational knowledge and adaptation (cargo, bunkering)
– ISPS knowledge and adaptation
– MARPOL/Environmental knowledge and adaptation
– Reporting
– Knowledge and adaptation on safety rules (General)
– Carefulness (General)
– Implementation the Company instructions / timing
– Team culture

Professional Behavior evaluation criteria:

– Cooperation and sharing knowledge
– Behavior, relationships with inferiors / superiors
– Adaptation of marine usage and customs
– Taking lessons from mistakes
– Loyalty to the Job & Company
– Computer knowledge & skill

Leadership and Social Behavior evaluation criteria:

– Adaptation to Sea and Ship Life
– Reliability

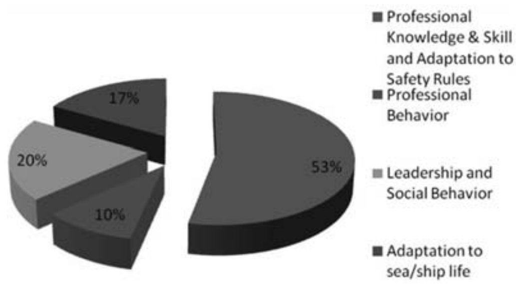

Figure 1. Priority of criteria groups for senior officers.

– Motivation ability and follow events, peoples and judgment
– Sharing Responsibility
– To share his/her knowledge and instructiveness
– Could he/she shortly explain his/her request. Speech ability
– Individual improvement / Has effort to improve the System
– Personnel cleanness
– Apparel/presentable and keeps clean his/her cabin/associate
– Adaptation to sea/ship life group criteria:
– Suitability to job basis health/physics
– Adaptation on Drug and Alcohol policy
– Adaptation on sea life

The priorities of evaluation groups for senior officers are shown in figure 1.

3.3 *Officer and other crew evaluation criteria*

The Following Evaluation factors are observed for junior officer group; rating group and cook & steward groups evaluation:

Professional Knowledge & Skill and Adaptation to Safety Rules group criteria:

– Profession knowledge (General)
– Profession experience
– English level
– Hand skill and use of equipment
– Understanding talent and application
– Work planning & timing
– Knowledge of equipments and maintenance
– ISM knowledge and adaptation
– Operational knowledge and adaptation
– ISPS knowledge and adaptation
– MARPOL/Environmental knowledge and adaptation
– Knowledge and Adaptation on safety rules (General)
– Carefulness
– Participation to drills and achievement
– Safety &Team culture
– Computer knowledge& skill
– Professional Behavior evaluation criteria:
– Cooperation and sharing his/her knowledge
– Behavior, relations to his/her inferiors

Figure 2. Priorities of criteria groups.

– Adaptation to sea & ship tradition
– Taking lessons from mistakes
– Loyalty to the Company

Leadership and social behavior evaluation criteria:

– Reliability
– Individual relationships
– Capability of explain his/her request. Speech ability
– Motivation ability and follow events
– Sharing Responsibility
– Personnel cleanness
– Apparel/presentable and keeps clean his/her cabin/ associate areas
– Adaptation to sea/ship life group criteria:
– Suitability to job basis health/physics
– Adaptation on Drug and Alcohol policy
– Adaptation on sea life

The weighting of evaluation groups is different for all seafarer groups. The priorities of evaluation groups for junior officer group, rating group and cook&steward group are shown in figure 2.

3.4 *Trainings*

26 different trainings that can be given in a chemical tanker management company observed. These trainings and training codes are:

1 Environmental Officer Training Course
2 Incident Investigation
3 Safety Officer Training
4 Shipboard Familiarization
5 Rescue Techniques from Confined Spaces
6 Lifeboats
7 Keeping Up Standards
8 Ship Vetting Inspection
9 Chemical Tanker Operation
10 Safety and Pollution Prevention
11 MARPOL and Environmental Protection
12 Chemical Tank Cleaning & Inspection
13 Search Techniques
14 Crisis Management
15 Marine Risk Assessment
16 Permit to Work Systems
17 Recognizing Suspicious Behavior
18 Identifying Explosives and Weapons
19 Watch keeping
20 Maintenance
21 Nitrogen Generator and Inerting
22 Bunkering
23 Drug and Alcohol Policy
24 Requisition
25 Hygiene on Board
26 Company Policies and Procedures

Table 1. Scores and trainings to be given.

CRITERIA	VG	G	M	P	VP	Training No
Knowledge of equipments	5	4	3	2	1	07-24
Evaluation and Timing of requisitions	5	4	3	2	1	07-24-26
ISM knowledge and adaptation	25	20	15	10	5	03-04-20
Operational knowledge and adaptation	15	12	9	6	3	9-12-20-21-22
ISPS knowledge and adaptation	5	4	3	2	1	2-13-14-17-18

4 MAIN CHARACTERISTICS OF DEPEDES (SETS) SOFTWARE

The main idea of Seafarer Evaluation and Training Software (SETS) is firstly to measure the performance of seafarers quantitatively then to give necessary trainings according to their scores. The program recommends different trainings for each rank and scores. The weighting of factors which are computed by utilizing AHP is enlarged to meaningful marks. Likert scale was used for marking. The scores of criteria and trainings to be given according to evaluation is shown in Table-1.

According to the columns, marks are shown in VG 'Very Good'; G 'Good'; M 'Moderate'; P 'Poor' and VP 'Very Poor' columns. The numbers shown in mark columns are the weightings of each score. The yellow marks shows training needs and the red one's show dismissal suggestion that should be discussed by the management. The column 'Training No' shows the training numbers which are described section 3.4 of this paper. SETS software is developed by utilizing Visual Basic programming language. The program is using 'if-then-else' rule codes such as:

```
'k 13 Knowledge
If q61.Value Then
Knowledge.Fields("k13") = 15
ElseIf q62.Value Then Knowledge.Fields("k13") = 12
ElseIf q63.Value Then Knowledge.Fields("k13") = 9
ElseIf q64.Value Then Knowledge.Fields("k13") = 6
ElseIf q65.Value Then Knowledge.Fields("k13") = 3
End If
```

The Seafarer Evaluation and Training Software (SETS) can also lists and graphically shows seafarers' scores according to their rank groups and scores, working dates and etc. Evaluation and Training Module of SETS is shown in figure 3.

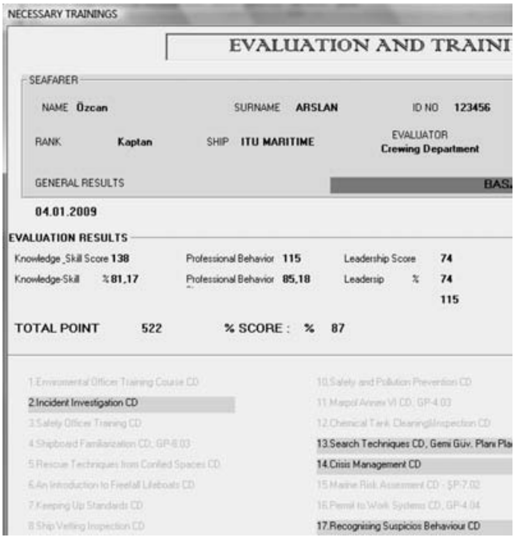

Figure 3. SETS software.

5 CONCLUSION

The main aim of this study is to improve the seafarer evaluation during sea period and consequently enhancement of safety and ship management performance to prevent accidents and casualties in maritime transportation by utilizing SETS software. It should be considered that the evaluation criteria; priority of criteria; trainings that can be given by the company and training needs can vary among different ship management companies. This software is prepared considering the capacity and needs of chemical tanker Management Company

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

16.8 MET system in Ukraine

M.V. Miyusov & D.S. Zhukov
Odessa National Maritime Academy, Odessa, Ukraine

ABSTRACT: It is believed that Ukraine is one of the largest seafarers' suppliers to the world maritime fleet. The vast and diverse system of waterways and lakes in addition to the tradition of seafaring and maritime history which dates back more than 200 years create the necessary basis for the government which considers it more important to provide graduates with the full education rather than merely to produce 'vocational' specialists. Moreover Ukraine has already made some major steps on the road to Euro integration having taken part in the Bologna process. Therefore it's not surprising that on 15 January 2005 a new resolution of the Cabinet of Ministers of Ukraine was approved. The Odessa National Maritime Academy(ONMA) was the first to visualize it by means of the new-presented system of MET.

1 THE OBJECTIVES OF MARITIME EDUCATION ESTABLISHMENTS

The licensed officers' staff is educated and trained by maritime colleges, academies and universities.

The training and education are effected for both operational and management levels. The International Convention on Standards of Training Certification and Watch-keeping for Seafarers (STCW-78/95) and STCW-95 Code established uniform international requirements to the training of ship watch-keeping officers and ratings Chapters II, III and IV of the STCW-95 Code present the mandatory minimum requirements to the competence of every candidate for the acquisition of Certificate of Competence enabling a person to occupy officers' positions on board.

The procedures to prove the officer's achievements of the required competence standard are defined and the criteria for evaluating the competence are listed in the corresponding tables of STCW-95 Code.

In combination with on-board practical training the above knowledge and proficiency enable a candidate to occupy corresponding officers' positions on board.

The curricula of the maritime educational establishments were adjusted in accordance with STCW-78/95 Convention requirements and since 1998 applied in most states. IMO developed model courses of training masters, deck and engineer officers (Model courses 7,01, 7.02. 7.03 and 7.04.) facilitated the transition to this order of training.

At the same time the opinion of the international maritime community, expressed at the conferences on maritime education in Sweden 2000 [4], in Belgium 2002 [5], and etc., shows that the minimum knowledge and proficiency requirements listed in STCW-95 Code are compulsory but not sufficient to satisfy the needs of the modern merchant marine.

The rapid development of fleet, specialization of ships, fitting them with complicated equipment, automation and electronics require the presence of specialists fundamentally competent in natural and technical sciences on board a ship. An educational establishment shouldn't be aimed at giving a certain fixed scope of knowledge for the operation of a modern vessel.

This knowledge will get outdated still before a prospective officer graduates. A maritime specialist should be prepared for being capable of understanding all the innovations and learn to operate them by himself. That is why the curricula of advanced maritime higher educational establishments include not only the minimum scope of knowledge and skills, which could have been covered in two years, but also two additional years of studies (bachelor's level) ensuring a broad general education.

Still another additional course of studies is required for the occupation of shipboard positions at the management level.

It's worthy to note, that the specific character of work on board – long periods at sea, reduced crews, hard work, sometimes driving those on board to stress situations and fatigue accumulation requires from a ship officer for the successful work with people to be well prepared in humanitarian aspects, that is to have a high cultural level, knowledge of psychology, the laws of a person's behavior in a group, ability to predict and eliminate conflict situations, optimize the relations among the seafarers united into one crew.

The majority of maritime higher educational establishments, especially those in European countries adopted the above educational system for training marine officers. A wide scope of education is necessary to ensure safe navigation in modern conditions.

We understand that to fit his future work on board, a seaman should not only have a high level of spiritual development, but also be well hardened physically. That is why maritime educational establishments devote much attention to the physical training of the future seafarers.

Besides regular general physical training and achieving the compulsory standards provided for by curricula, favorable conditions are provided for training in different sports up to the choice of a young man. All sorts of sports competitions at different levels are greatly encouraged by the administration.

The quality of preparation of the seamen for their future work on board ships largely depends on the lecturers and instructors; in compliance with the STCW Convention those are to have the proper qualification for different types and levels of education and training.

Lecturers and instructors specialized in professional disciplines should have not only an appropriate maritime education but also a sufficient sea experience. That is the matter of especial importance, as it enables them besides delivering a theoretical course, to share their acquired experience for training the cadets (students) to solve routine operational problems in practical way, fostering proper care and attention to their every day work, responsibility for the fulfillment of their duties on board.

Unfortunately the payment of lecturers and instructors is much lower than that of seafarers on board.

That is why it is very difficult to attract properly qualified experienced maritime industry practicians still not of old age to the academic work in maritime educational establishments.

Besides not every experienced practician is capable of resultative lecturing or practical training.

Taking into account the above problems IMO has developed special methods of preparing maritime officers to academic career which help them to learn methods of training the young people both on board and shore.

One of the ways of attracting experienced practicians, first of all masters and chief engineers to academic activity may be their invitation to the engagement in the educational establishments during the periods of their stay on shore between the contracts concluded for the work at sea. A solution of the problem would also be the arrangement of a temporal refresher employment of the lecturers in the position of dubbing officers or their temporal employment to the crew staff positions on board commercial ships, but that requires certain funding, which an educational establishment is mostly short of as well as understanding and support on the part of shipping companies.

2 MET IN THE UKRAINE

The two principal factors – the alarming situation with the employment of population and low rates of pay for labor on the one hand and the high standards of education and training of marine officers in Ukraine on the other hand predetermine favorable opportunities of training competitive specialists for the international labor market in the maritime educational institutions of Ukraine. Mostly part of the graduates from ONMA were employed for service on board ships under foreign flags. However, many specialists after gaining invaluable practical experience in Ukrainian companies seek employment by foreign shipowners. The laws on the employment and on the higher education currently m force in Ukraine enable a graduate of a higher educational establishment to effect a free choice of the employment place. The latter fact gives the graduates of the Maritime educational establishment the opportunity for the employment by foreign shipping companies.

Ukraine, as a maritime power, being a party to the STCW-78.95 International Convention has undertaken to constantly maintain the quality of training seafarers at the level of international standards.

The achievement of these standards has only become possible as a result of creation of a proper national system of education and training, refresher and upgrading courses and courses of additional relevant education and training for officers. This system comprises today 10 Maritime higher educational establishments (academies, universities, institutes and colleges) and about 40 maritime training centers, most of them being fitted with advanced simulator base and modern training technologies.

Odessa National Maritime Academy is the basic educational establishment of Ukraine. It educates and trains wide profile maritime specialists for both national and international labor market. All the conditions are created in the Academy for training specialists meeting the requirements of the international standards of shipping industry, requests of national and foreign shipping companies.

ONMA amounts about 11000 undergraduates of seafaring specialization with yearly graduation more then 1000 people. The Academy comprises faculties, institute, colleges and training center, not only in Odessa but in other cities of Ukraine.

Enrollment based on the competitive choice of candidates having complete secondary education 10–11 years).

Term of studies of a specialist having complete higher education -5.5 years;

Provision of on-board training not less than 8–12 months depending on the special field;

Fundamental general engineering training;

High level of educational technology provision;

High rating of the academic stuff;

Combination of studies and research work of the cadets, development of creative skills;

Arrangement of studies and even' day life of cadets in the conditions resembling shipboard environments and routines;

Compliance with the requirements of the international conventions;

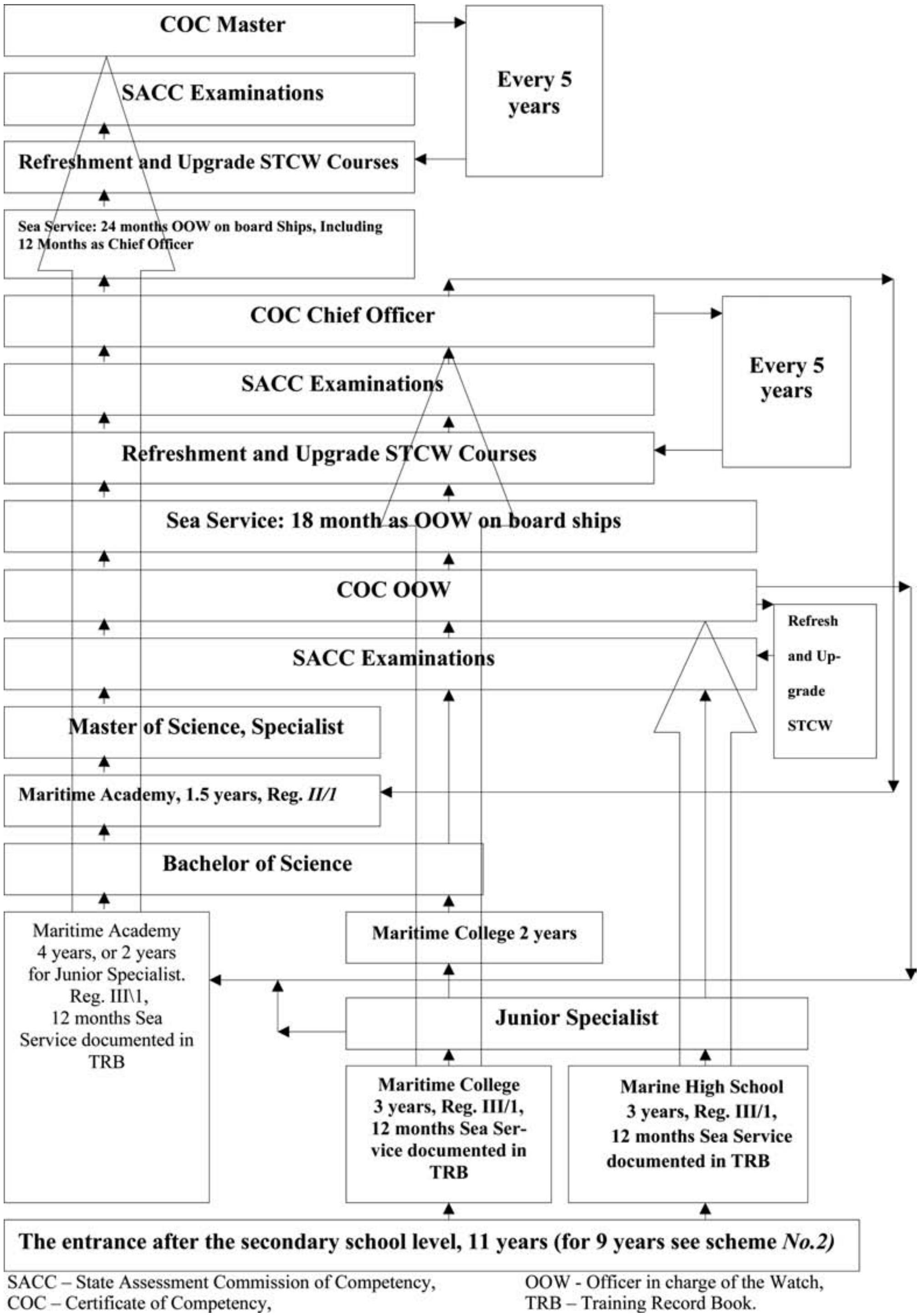

Figure 1. The Unlimited Certificates of Competency (Deck) – Referring to the STCW 78/95 and Resolution of the Cabinet of Ministers of Ukraine No 38, 15th of January 2005 – "Regulation on the Conferring the rank upon the Ukrainian Seafarers".

System of continuous post-graduation education for marine officers for maintaining a high level of competence, familiarization with new technologies and new control methods.

The last decade reforms of education in Ukraine initiated the transition to the stepped system of training specialists, providing for four qualification educational levels: junior specialists, bachelor, specialist and

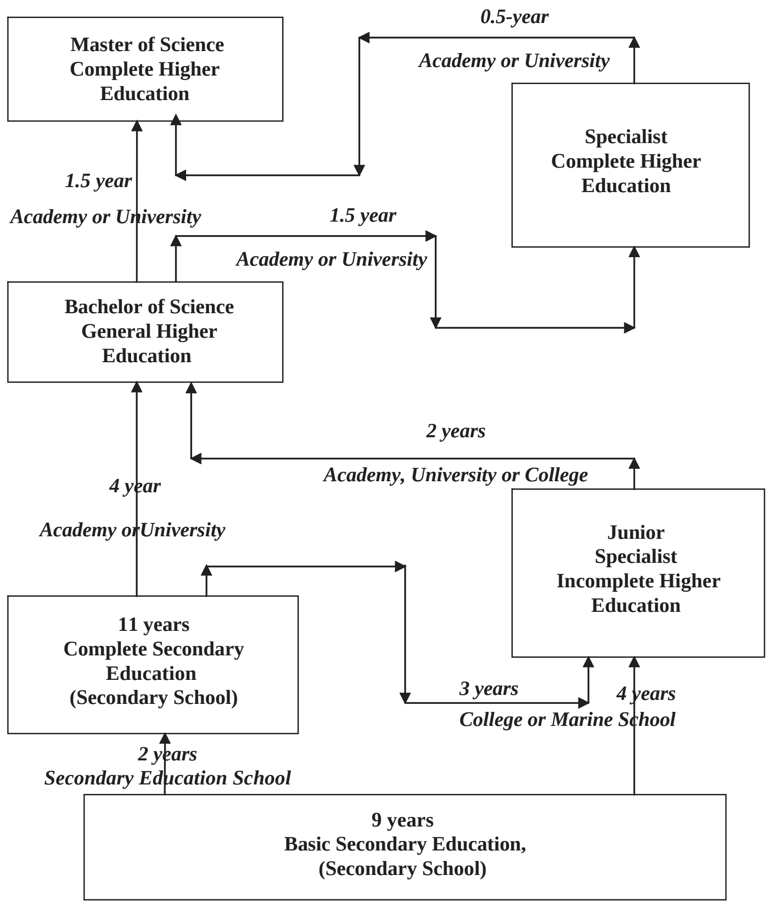

Figure 2. The System of Education in Ukraine.

master. According to the conception of education and professional training of ship crew members, approved by the Ministry of Education and Science of Ukraine, the graduates of the educational establishments at the level of junior specialists and bachelor shall occupy on board the positions of officers in charge of a watch at the operational level and those at the level of specialists and masters at the management level in compliance with STCW-95.

3 PRACTICAL TRAINING OF CADETS

STCW-78/95 Convention (Section B-II/1) notes that the mandatory periods of seagoing service are of prime importance in learning the job of being a ship's officer and in achieving the overall standards of competence required. The programme of on-board training should be an integral part of the overall training plan, The improvement of quality and systematic character of practical training are facilitated by an individual "Training Record Book" proposed by IMO. It will provide unique evidence that a structured programme of on-board training has been completed, which can be taken into account in the process of evaluating competence for the issue of a certificate. The Convention provides for two identifiable individuals who are immediately responsible for the management of the programme of on-board training. The first of these is a qualified seagoing officer, who, under the authority of the master, should organize and supervise the programme of training on board, the second should be a person nominated by the company, referred to as the company training officer. He should have an overall responsibility for the training programme and for coordination with colleges and training institutions.

The company should ensure that appropriate periods are set aside for completion of the programme of on-board training and bear the whole of the expenses for practical training of the prospective maritime officers to be further employed by the company.

A certain part of the shipping companies act in the compliance with the requirements of the Convention, taking an active part in training maritime specialists, place cadets on their ships for on-board training, nominate officers responsible for the management of the programme of on-board training, bear the burden of expenses for the provision and transport to embarkation place and (for repatriation) of cadets. It's necessary to note that such activity not only facilitates good practical training of the prospective officers but also a current operation of ships with the help of the cadets which perform any feasible works on board and form part of a watch. At the same time the company has a chance to evaluate prospective officers they intend to employ after the graduation.

Unfortunately far not all companies find vacancies for cadets, and are engaged in their training on board. It would be desirable to work out an agreement at the international level recommending the shipowners to place cadets on every ship.

It is worthy to note that the European Conference on Employment and Training 2001 held in Tallinn by LSM Company(Lloyd Ship Management) insistently recommended shipowners to reserve minimum two vacancies per ship for cadets and also to invest money in education and training of seamen "invest in people" [3].

ONMA has gained an experience of direct contact and cooperation with the shipping companies, which make a choice of last-year cadets of the Academy, support them in the final stage of their education and in this way form a reliable manning reserve of deck and engineer officers, to be employed by these shipowners after their graduation.

The results of the active position of the Academy in the international co-operation are not limited to the provision of our cadets with the vacancies for practical training on board foreign vessels with substantial remuneration for their labor and social guaranties: but they extend to concluding direct contracts with shipping companies providing for the financial aid to the Academy.

In 2008 above 3500 cadets of the Academy completed the programs of their on-board training including 2000 on board ships belonging to foreign shipowners.

The policy of the company provides for the eventual employment of the cadets after their graduation in case of successful completion of two terms of shipboard practical training on board the ships belonging to the Company. More then 100 contracts on the on-board training have been signed with different shipowner Company.

4 CONCLUSION

A comparatively short period of time is necessary for building a fleet, but a longer period is required for bringing qualified officers to maturity. A common concern of crewing companies, maritime institutes and training centers is the assurance of the high level of seafarers' competence.

The shortage of qualified officers also requires the revision of the policy of shipping companies. Comparatively insignificant investments in education, training and upgrading of seamen within the framework of appropriate programs of personnel formation and control would give priority in provision with staff to those companies which assure their future and "invest in people".

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Chapter 17. Maritime policy, proposals and recommendations

Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

17.1
The Somali piracy new or old challenge for international community

D. Duda & T. Szubrycht
Polish Naval Academy, Gdynia, Poland

ABSTRACT: Nowadays it is obvious that maritime transport is the core element of word economy so each disturbance in the world shipping can create more or less serious problems for world economy, especially now when the world crises appeared. The piracy activities showed that shipping safety in the Gulf of Aden and waters around the Somalia should be considered as an international problem. The Somali piracy has complex reasons, so it is not easy to provide safety of shipping in this region without wide spectrum of action and international cooperation. The paper presents analyze of piracy root in Somalia, the development of piracy activities and steps of international community which should be taken to provide safety and secure shipping in this region.

1 INTRODUCTION

Somalia – a country in Eastern Africa has a strategic location on Horn of Africa, along southern approaches to Bab-el-Mandeb and shipping route through Red Sea and Suez Canal. Somalia is bounded to the north by the Gulf of Aden, to the south and east by Kenya, to the west by Ethiopia, to the northwest by Djibouti and finally to the east by the Indian Ocean. The country has 2,340 km land boundaries (Djibouti 58 km, Ethiopia 1,600 km, Kenya 682 km) and 3,025 km of coastline.

The total area of Somalia is 637,700 sq km; the country has a population (2005 estimate) of 8,6 million. Population counting in Somalia is complicated by the large number of nomads and by refugee movements in response to clan warfare. The main ethnic groups are: Somali 85%, Bantu and other non-Somali 15% (including Arabs 30,000). Islam is the state religion in Somalia, and most of the people (90%) are Sunni Muslims, a Christians (mostly Roman Catholic) are less than 1% percent of ethnic Somalis. Mogadishu (the capital of Somalia), Hargeysa, Kismaayo and Marka are the principal cities of the country (CIA word factbook).

Uranium and largely unexploited reserves of iron ore, tin, gypsum, bauxite, copper, salt, natural gas and oil reserves are main natural resources of the Somalia (CIA word factbook).

It is said that Somalia was an example of fallen country, because the legal government was not able to effectively execute the power over the territory of the country.

Figure 1. Somalia and the political fragmentation of the country in the beginning of XXI century.
Source: http://geography.about.com/library/cia/blcsomalia.htm, http://www.globalsecurity.org/military/world/war/somalia.htm

2 ROOTS OF THE PIRACY IN SOMALIA

Of course the piracy problem should not be limited only to waters around Somalia, because it is a worldwide problem, but now the Somali piracy problem is the most popular in world media, so the authors decided to focus the analyze only in the waters around Somalia. The maritime area around the Somalia is very important for world economy. Almost 11% of the world's seaborne petroleum passes through the Gulf of Aden and waters around the Somalia. It shows the importance of Somali waters for world economy.

The country has been without a strong central government since 1991, when the Mohammad Siad Barre was ousted after 22 years in power. Since that time the political situation in the country is similar to puzzle. The state collapsed into chaos and criminality, Somalia had been a field of fight for power between numerous clans, subclans and religious fractions. The country has been suffering from war, instability and natural and humanitarian disasters.

We should not see piracy off the coast of Somalia only as a result of the continuing political instability and lawlessness in this country.

It must be said, that the Somali piracy was also closely connected with economical situation of Somali people and problems with over fishing and toxic waste disposal around Somalia.

There are the highest concentrations of fish in the waters around coast of Somalia. Somali fishermen used to catch a wide variety of seafood (tuna, sardines, dorado, perch, shark and lobster). At the turn of the millennium, Somalia was home for about 30,000 professional and 60,000 occasional fishermen. Fishes were traditionally export products of Somalia. Now (because of instability and permanent war in Somalia) about 700 ships from other countries, are casting local fishermen nets along Somalia's coastline, and they show a little consideration for the fish stocks, local fishermen or over fishing. None of the foreign trawlers has a license for fishing around Somalia. Today trawlers from faraway places continue to ply the waters off the long coastline. There are ships from Japan, India, Italy and Spain and others countries (http://news.bbc.co.uk/2/hi/africa).

This fishing activity is named by Jeylani Shaykh Abdi, a Somali fisherman, as an economic terrorism. He said „They are not just robbing us of our fish. They are ramming our boats and taking our nets – including the catch". According the Somali people, the intruders, used nets with very small mesh sizes and fished with banned dragnets, and with dynamite in some cases. The Somali fishermen outcry to the United Nations and the international community was loud and clear – but without any results. The Spanish fishing cutter that pirates hijacked in May 2008 and the Thai trawler which was sunk by Indian warship in early November provided evidence of how attractive the Somali fishing area is worldwide.

Somali fishermen have also problem with toxic waste. The huge amount of toxic waste was dumped at sea after the collapse of the regime of former President Siad Barre in 1991. Because the country has no coast guard, the Somali coastline has no protection against European ships dumping dangerous waste at sea. Proper waste disposal in Europe costs about 400 times more than illegal waste dumping in Somalia. That toxic waste has been dumped in Somalia for a long time, and the international community is looking on and "doing nothing about it". So the international community gives the pirates "a convenient excuse to legitimize their actions".

The Somali pirates have repeatedly argued that they were forced into piracy by the demise of fishing and the practice of dumping toxic waste at sea. But it is not the main reason, only a small fraction of traditional fishermen have switched to piracy.

Nevertheless, toxic waste and illegal foreign fishing are convenient arguments for the pirates. Januna Ali Jama, a spokesman for the pirate group said that "We are still waiting for its ransom for the *MV Faina* (pictures 2), a Ukrainian vessel carrying tanks, weapon and military equipment. All we do is ask ransoms for the ships we hijacked because we believe a ransom represents a legal tax that a government may have taken.

Figure 2. Somali pirates in small boats hijacked the arms-laden Ukrainian freighter *Faina*.
Source: United States Navy, via Agency France-Press – Getty Images.

We are defending our waters from foreigners dumping toxic waste and plundering our sea resources. I hope the world can understand that this is the responsibility of Somalis and we shall one day be rewarded for our efforts. The Somali coastline has been destroyed, and we believe this money is nothing compared to the devastation that we have seen on the seas" (Somali pirates: Sea bandits or coastguards).

The Somali piracy activity is similar to avalanche. Back in 2005, there were almost 100 gunmen. Now (in 2008) there are between 1,100 and 1,200 pirates (http://news.bbc.co.uk/2/hi/africa).

Without naval or coastguard forces patrolling its EEZ, local fishermen turned to piracy to stop illegal fishing and toxic dumping in Somali waters.

But there is another point – pirate life is attractive for many young men in this one of the poorest countries on the planet. The profits from piracy are immense. The men carrying out the hijackings keep about 30 percent of the ransom money (20 percent goes to the bosses, 30 percent is paid in bribes to government officials and 20 percent is set aside for future actions). "He used to be a poor fisherman a year ago but now he is rich. He bought three beautiful houses in the same neighborhood. He had a wife but married a second one recently. There were maybe 150 cars in the wedding convoy. He is pirate now (http://news.bbc.co.uk).

"If you ask around, everybody will tell you pirates are bad. But that's just in the conversation," said Haji Abdi Warsame, an elder from the coastal town of Eyl, a major piracy hub on Somalia's Indian Ocean coast (Somali pirates: Sea bandits or coastguards).

Corruption is also important factor of piracy. Historical analyze of piracy shows that corruption was the key element (both in ancient time and modern history). "Presumably, all key political figures in Somalia are profiting from piracy" said Roger Middleton, an analyst with the Royal Institute of International Affairs in London. "This is just like any business for us. We care about it just like anyone would care about their job. I have been on the ocean for a long time, not to fish but to hunt down ships in our territorial waters, which nobody will guard if I don't do it," he explained (http://news.bbc.co.uk/2/hi/africa). All those reason shows how complex is the problem of piracy in this part of the world.

So if we (international community) want to stop piracy, we should not only fight with pirates. We need to stop all illegal activities as well.

3 SPREADING THE AREA OF PIRACY ACTIVITIES

Few years ago the main targets for piracy were both fishing boat which according the local Somali population provides illegal fishing in the Somali Economic Exclusive Zone (EEZ) and vessels, which were suspected of illegal toxic waste disposal. At that time the pirates attacked vessels no farther than 50 miles way of the coast.

The first reaction of ship owners for piracy attacks was to increase the distance of shipping line from the coast. But the pirates changed their tactics; they started to use the mother ship. They attacked vessels farther and farther from the coast. While previous attacks took place within 200 nautical miles away from land, now even the ships sailing 400, 500 or event 600 miles away from the coast of Somalia are not safe. Also the size of the vessel doesn't matter. The *Sirius Star* supertanker (332 meters), owned by Saudi oil company Aramco, was hijacked roughly 450 miles southeast of Mogadishu (pictures 3).

There is an interesting question why the hijacking act of the *Sirius Star* had so great impact on the world mass media. Why was this accident so famous?

Last year took place many other important but less spectacular piracy actions, for example in September, Somali pirates captured in the Gulf of Aden a *MV Faina* Ukrainian vessel with 33 tanks (T-72) and other military equipment. According to the latest International Maritime Bureau (end of the November 2008) data in the 2008 more than 110 vessels have been attacked around Somalia. The pirates captured 42 ships, 286 crew members remain as hostages following attacks in the Gulf of Aden and waters around the Somali coast. Negotiations to free 14 ships are on-going. The piracy accidents in Gulf of Aden and waters around Somalia are presented in the table 1. It is easy to notice that in other region the piracy threat is bigger than in the waters around Somalia.

There is a simple answer for this question. The 1,800 feet long *Sirius Star* tanker, can carry about 2 million barrels of oil and is one of the largest ships in the world. The ship's cargo is worth about 100 million USD. The pirates showed that now global sea-borne trade of strategic resources could be threatened. This is the main reason why Somali pirates and their actions are present in headlines of international media. The case of *Sirius Star* showed that "these new piracy events are a signal about the security situation here – if the piracy can go 400 miles out to sea, they can go 600 miles, and they can go anywhere. To find a solution to the escalating security situation, first of all we need to established cooperation between all contributing navies more efficient. […] we also need to make sure that all navies can act with similar rules of engagement" (Zoro Jane's Defence Weekly, 26 November 2008).

Table 1. Piracy and armed robbery against ships.

	2003	2004	2005	2006	2007
Gulf of Aden and Red Sea	18	8	10	10	13
Waters around Somalia	3	2	35	10	31
Nigeria	39	28	16	12	42
Indonesia	121	94	79	50	43
Total in the world	445	329	276	239	263

Source: ICC International Maritime Bureau piracy and armed robbery against ships annual report 2007.

Figure 3. Tanker *Sirius Star* and satellite imagery of the tanker anchored near Gaan on the Somali coast.
Source: http://bbs.keyhole.com/ubb/showflat.php/Cat/0/Number /1242871/an/0/page/0.

4 INTERNATIONAL ACTION TAKEN TO DECREASE THE SOMALI PIRACY THREAT

The problem of Somali piracy is complex and there are different proposals how to increase the shipping security in the Gulf of Aden and water around Somali coast. The international community tries to take wide spectrum of actions against piracy in this area. Some of the actions are obvious some are rather controversial. Nowadays we can say that international maritime community took such actions for shipping protection as:

- multinational (CTF 150), NATO (Standing NATO Maritime Group 2) and EU NAVFOR (Operation ATLANTA) naval task forces;
- protection of vessels by private military contractors and armed guard on merchant vessels;
- non-lethal self-protection methods;
- reflag of the vessels;
- change the shipping lines.

Combined Task Force 150 (CTF 150) has been established in 2003 to monitor, inspect, board, and stop suspect shipping in the Gulf of Oman, Gulf of Aden, Arabian and Red Sea and finally Indian Ocean (picture 4).

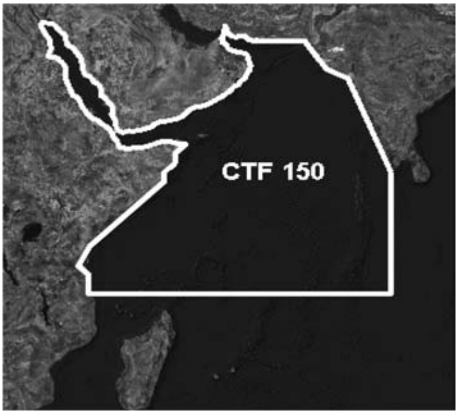

Figure 4. The area of responsibilities of CTF – 150.

The CTF 150 area of responsibility is 6,2 million sq km and includes the crossing of main world oil and gas shipping lines. There are three choke points of world oil and gas transport: Sues Channel, Badel-Mandab and Hormuz. The eastern and northeastern Somali coast are high – risk areas for piracy attacks and hijackings for ransom. According western analyses it is also area of drug smuggling and important area of counterterrorism mission. Commodore Bob Davidson (Canadian Navy) Commander of CTF 150 identified the three highest priorities for CTF 150:

- maritime security operation, which he calls "the classic counterterrorism mission";
- counter-piracy operation;
- counter drug missions (drug money is going back to either the Taliban or Al-Qaeda).

He added that "there are no restrictions to taking action once pirates get on board and there is a hostage situation. Another challenge is if the vessel that has been taken has gone into Somali waters. Under the law of the sea prior to the UN resolution, act of piracy inside territorial waters is not a piracy act but armed robbery and therefore it is a local law-enforcement issue" (Newell Jane's Defence Weekly, 17 September 2008).

The task forces usually consist of several ships (destroyers, frigates and auxiliary ships, helicopters and maritime patrol aircrafts) from such NATO countries as: Canada, France, Germany, Greece, Italy, Netherlands, Portugal, Spain, Turkey, United Kingdom and the United States. Ships from such non NATO countries as: Pakistan, Australia, New Zealand, Sweden, India, Malaysia, Russia and China also participate in counter-piracy operation. The command of the task force rotates between the different participating navies, and usually last between four to six months. It is easy to notice that for each participant countries the area of CTF – 150 responsibilities is vital for economical prosperity. Commodore Davidson said that "We want to show Canadian interest in the region not just in Afghanistan but in the maritime world as well" (Newell Jane's Defence Weekly, 17 September 2008).

The head of China's National Defence University major-general Jin Yinan said "I believed the Chinese navy should send naval vessels to the Gulf of Aden to carry out counter-piracy duties. With China as a major world economy, it's very difficult to say that security problems across the world have nothing to do with us. If we don't take effective action, how will they see us abroad, and how will Chinese people view their government?" (Frank, Lloyd's List, 5 December 2008).

Also the Council of the European Union (EU) announced on 10 November its intention to proceed with the first deployment EU naval task force for counter-piracy operations off Somalia. The mission is also opened to non-EU participation. Up to six vessels including three frigates and supply ship plus three or more maritime surveillance aircrafts are expected to join EU NAVFOR Somalia for Operation Atlanta in December 2008. This year-long mission will provide escort protection for civilian vessels delivering food to displaced people in the war-torn country as a part of the UN World Food Program.

One month after the Council of the European Union decision the German government decided to contribute in the counter-piracy mission Atlanta with 1400 soldiers and frigates. The navy would also be allowed to arrests pirates and bring them to trail in Germany, said home secretary Wolfgang Schäuble. (Fish, Jane's Navy International, December 2008).

The EU NAVFOR counter-piracy task force will in some circumstances provide free armed guards to protect vulnerable merchant vessels in the Gulf of Aden, as a part of its response to the explosion in piracy close to Somalia. But there is important question what does vulnerable merchant vessels mean? NAVFOR officials stressed that World Food Program (WFP) ships would have first call on military resources. The Royal Netherlands Navy had deployed in the end of November frigate HrMs *De Ruyter*, which escorted two WFP vessels on its missions from Kenyan port of Mombasa.

Also NATO joined to counter-piracy operation in the area around Somalia. Three warships from Standing NATO Maritime Group 2 have begun escorting WFP vessels carrying aid to Somalia. The NATO group consist of the Hellenic Navy's frigate HS *Themistocles*, the Italian destroyer ITS *Luigi Durand De La Penne*, and RN's frigate HMS *Cumberland*.

The NATO ships since early November have been operated under newly adopted joint rules of engagement (ROE). The new NATO ROE and operating plan are addressing to counter-piracy efforts and escort responsibilities for ship carrying humanitarian assistance organized by WFP to the more than three million Somalis. The new ROE is sensitive to their national commands, which allow navies to board vessels suspected of illegal acts and confiscated illegal weapons. According to NATO spokeswoman Carmen Romero, it means the ability to arrest, detain people suspected of being pirates (Zoro, Jane's Defence Weekly, 26 November 2008). There are many examples that use of force may create serious political problems.

Below there are examples of different military action, which were taken by ships in last two months of 2008.

The Indian Navy ship INS *Tabor* sank a pirate "mother ship" on November 18, after coming under heavy fire from pirates. But two speed boats laden with suspected pirates escaped. The "mother ship" was a former Thai trawler, boarded by pirates. The Thai crew members were killed during the fight between pirates and Indian ship. This accident has caused embarrassment to the Indian Navy, and may have serious impact on future naval responses to Somali piracy.

On 25 December the German frigate *Karlsruhe* received distressed signal from crew of Egyptian vessel *Wadi al-Arab*. The vessel was under piracy attack 50 miles off Yemeni coast. The German ship sent the helicopter to support the crew of *Wadi al-Arab*. The pirates escaped when they saw the helicopter. After few hours the *Karlsruhe* stopped the piracy motor boat and captured six pirates. But the German government ordered to free pirates who were captured by German sailors. The spokesman of EU NAVFOR captain Achim Winkler said that "the pirates could by arrest and sent to Germany only if they attack German vessel or the German citizen would be injured during the piracy attack" (Kuźmicz, Gazeta Wyborcza 18 grudnia 2008).

On 2 December Danish ship *Absalon* rescued a group of suspected pirates in the Gulf of Aden after receiving a distress signal from their vessels, which had technical problem in heavy seas. According the international law *Absalon* had to help the vessel. The Danish sailors discovered a number of weapons onboard the vessel, similar to those which are often used in pirate attacks on merchant ships. Due to weather, it was impossible to take the ship in tow and vessel was sunken in the interest of shipping safety. The pirates were later handed to authorities in Yemen.

The military actions, which were taken by ships from different countries, show the different aspects of military action in the maritime area around Somalia.

Commodore Bob Davidson said that "It is a mission that is part operational, part diplomacy, but it really is about building co-operation in the region" (Newell, Jane's Defence Weekly, 17 September 2008).

The government of the autonomous Puntland region on the west bank of the Gulf of Aden has also moved to respond to the piracy activity. Puntland troops boarded and recapture an Indian cargo vessel on 21 October 2008.

5 USING ARMED GUARD ON MERCHANT VESSELS AND ENGAGING PRIVATE SECURITY COMPANIES

There is another solution for increasing the shipping security – using armed guard on merchant vessels and engaging private security companies. A small but growing number of ship-owners are exploring the use of armed personnel to guard ships sailing through the waters of the Gulf of Aden. Private security contractors said that they were getting more queries from companies interested in their services, including the use of weapon. While the most maritime executives flatly refuse to even consider the presence of armed guards on their vessels, others seem to be seduced by the idea. "Some owners have a fascination with the concept of armed guards sailing on ships transiting the Gulf of Aden, but many ship-owners abhor the idea and, generally there is far more talk than action" (http://www.abc.). Using armed guard and engaging private security companies on merchant vessels raise many numbers of issues, from legal points to morality matter.

There is an opinion that we (international community) can not blame the ship owners for taking security measure into their own hands, but this is not the best answer for piracy threat. We will never have enough warships to protect the whole area – so we need to find a long-term solution that involves more efficient co-operation, designated escort lanes and getting to the mother ship if possible" (Zoro, Jane's Defence Weekly, 3 December 2008). There are around 20 ships in the water around Somalia, so each ship should take responsibilities for almost 300 thousands sq km. Company spokeswomen Anne Tyrrell said "We absolutely think it would be a good idea to employ such companies [private security companies]. US – based Blackwater Worldwide has already offered its service in the form of its own vessel. There have been initial conversations with 15 shipping companies but there have been no contracts signed" (Zoro, Jane's Defence Weekly, 26 November 2008).

To support the idea presented by Anne Tyrrell we can give many examples. One vessel was boarded while it was sailing in a French Navy convoy with three British unarmed security guards onboard, who were forced to jump overboard when they came under heavy fire. Andy MacDonagh, a director of private military contractor Raven Special Project said that for most people, contemplating the use of forearms was distasteful. But he said that non-lethal alternatives were not working. How do pirates in a small boat can stop a 30 000 tone ship? It is forearms, that all it is. But as soon as you fire back, they are going to turn round and go the other way because they are so vulnerable (Zoro, Jane's Defence Weekly, 26 November 2008).

But on the other hand there are quite different opinions in this matter. There is opinion that "The risk of engaging private security companies may increase the probability of potential casualties aboard" (Reyes, Lloyd's List, 4 December 2008). Hiring armed guards is a controversial step that goes against the advice of international shipping bodies, including the Round Table of industry associations and the International Maritime Bureau. Both organizations strongly oppose this option. There is a fear being expressed that it may not to be possible to control the actions of the armed contractors. We should stress that seafarers are not trained professionals in the use of weaponry. There are not regulations which ban weaponry on board of the vessels. Many countries have no express prohibition against arming the crew members. Although we should say that some country recommendation are for some are against. For example:

Registrar general of Jamaica Ship Registry Eric Deans said that "We do not have any explicit rules regarding the arming of ships. We leave the security of a vessel to the discretion of its owner".

Liberia – our policy is to discourage arming merchant ships, but Liberian law does not prohibit it and we will not do more than try to discourage it.

"The use of armed guards was not officially encouraged, it was not prohibited either" said spokesmen UK Ship Register.

Isle of Man "Manx flag neither encourages nor prohibit weapon".

Barbados Maritime Ship Registry principal registrar said "We have not got a position formulated, because it has not come up with any of our ships. It is a bit difficult; we would have to sit back and think it through" (Osler, Lloyd's List, 12 December 2008).

Head of security at the Chamber of Shipping Peter Hinchliffe said that France has informally offered armed guards for several months, as part of its loose escorting arrangements for group of ships (Reyes, Lloyd's List, 4 December 2008).

Blackwater private military contractors are ready to provide armed protection to vessels sailing close to coast of Somalia. British Concern Maritime and Underwater Security Consultants is understood to offer armed personnel, while stressing that such a policy should only be adopted in very specific circumstances, where vessels are judged particularly vulnerable, or the cargo carried is of high value.

But there is also another aspect of the problem. Putting EU military guard (or guard from private security companies) on vulnerable vessels in the counter-piracy operation in the Gulf of Aden may raise serious problems from an insurance viewpoint[1]. War risk insurers cover crew members killed or injured in pirate incidents but armed guards are not considered as a crew. The armed guards onboard may increase the insurer's fee for vessels sailing in this region.

6 CHANGE THE SHIPPING LINES OF THE VESSELS

More and more ship-owners consider the change of shipping lines to avoid this dangerous region. For example German cruise operator Hapag-Lloyd Kreuzfahrten will no longer operate vessels carrying passengers through the Gulf of Aden. Hapag-Lloyd Columbus had to passes through the Gulf of Aden on its round-the-world voyage. But all 246 passengers and most of the crew flew from Yemen to Dubai and stayed three days in five-star hotel in Dubai, while the Columbus passed through the piracy – ridden region with skeleton crew onboard. The ship kept a distance of 400 miles away from the Somali coast, as was advised by local authorities.

A large scale rerouting of vessels to avoid the threat of piracy in the Gulf of Aden besides the raise of cost could also lead to problems with fuel supply. The vessels sailing around the Cape of Good Hope can bunker the fuel in two places: South Africa or the Canary Islands. However, there is a difficulty to supply the vessels in South Africa, particularly after the fire that closed Durban's Engen Refinery in November. The refinery could be out for three months. Durban's Engen Refinery is one of the main suppliers of marine fuel in South Africa and other suppliers are also facing potential supply shortage. The bunker installation in Canary Islands is not developed for fuel supply for increasing vessels traffic. This limitation and economical aspect (raise of the cost) can the main obstacle for rerouting of vessels to avoid the threat of piracy in the Gulf of Aden.

7 NON-LETHAL SELF-PROTECTION METHODS

There are many different types of non-lethal weapon which can be installed on board of vessels. According the Chamber of Shipping operators should continue to explore non-lethal self-protection methods. First of all there is no legal restriction for using such weapons on the board of shipping vessels. There are several different types of such weapon, for example: long-range acoustic devices (LRAD), Active Denial System (ADS), Non-Lethal Slippery Foam and Dazzle Gun.

In early November 2005 about 160 km off the coast of Somalia pirates with RPGs and firearms attacked luxury cruise ship *Seabourn Spirit* but they not succeed. The crew used the LRAD to protect the vessel. The effectiveness of LRAD during the attack on was not completely clear, but the pirates did not succeed in boarding the vessel.

But there are also examples when the LRAD was non effective during the piracy attack. On 28 November the long-range acoustic devices LRAD which is the most popular and widely used as non-lethal weapon was ineffective during the piracy attack on the chemitanker *Biscaglia*. According the American Technology Corp (ATC) the main reason of the ineffectiveness was the number of LRAD's and its locations on the ship. Mr. Stuckey vice-president of ATC said "You cannot just strap an LRAD to the stern of a ship and expecting it to work throughout the vessel. What if I strapped a 50 caliber machine gun to the stern of the ship? How effective is that going to be at the bow? You have got superstructure in the way, and it is a significant distance forward. There is a lot blocking your path. But is it fair to say a machine gun is an ineffective weapon, or is it being ineffectively employed.

[1] Ship owners have to pay 10 times more insurance premiums for coverage of passage through the Straits of Aden.

One LRAD device on the chemitanker *Biscaglia* was placed in the stern. According the ATC because of his size the ship should have two LRAD (one on each board) and it should be place at the midships – not stern. Most attacks do not see pirates approach from the stern, but midships, where the bow waves are not such an issue" (Osler, Lloyd's List, 9 December 2008).

8 REFLAG OF THE VESSELS

Some ship-owners consider a possible switch away from flag of convenience towards national registries with credible naval assets. For example if a British flagged vessel is under attack, any British naval vessel in the area would have to respond. But it is also not a perfect solution, because military action against pirates on board of the vessel can be dangerous for crew. The naval specialists pointed out that such action from legal point of view can be complicated. It can be a serious dilemma for commanding officer to take or not military action. The nationality of the owner (vessels or cargo) and nationality of the crew members will be also a very important issue. Analyze of military action of naval ship shows that first of all naval ship provides protection for their national flag vessels. The security of the crew will be also a very important factor of the military activities.

9 CONCLUSION

There are many regions when the piracy activities have impact on world shipping. The modern piracy analyzes show that roots and piracy actions as well as counter-piracy operations all over the world in many aspects are similar but not the same. Of course there are general conclusions for piracy problems all over the world:

- roots of piracy;
- social, political and economical aspects of piracy;
- impact (especially economical) on world or regional shipping;
- types of counter-piracy activities;
- tactics of piracy attacks.

But because of political, military, social, economical, geographical factors the problem of Somali piracy has an individual and complex character.

According the authors it is not possible to solve the Somali piracy problem only by military means. The core element in counter-piracy operation in this region is political stabilization in Somalia. The international community and Somali government should take at the same time political, economical and military actions against piracy. The action against piracy should include such elements as:

- the political stability must be established in Somalia;
- the Somali government must received the military support from international community, but military cooperation should respect the sovereignty of Somalia;
- the international law of the sea should be obeyed by other countries;
- the country should received effective economical support for rebuilding the state economy;
- a comprehensive operation to eliminate armed robbery and other criminal acts against ships at sea should include the relevant operations on land;
- it should be a close cooperation between nation participating in counter-piracy operation;
- the ship owners should take the whole spectrum of activities which can increase the safety of the vessels.

It should be emphasized that the main goal of Somali pirates is ransom, so the risk for crew is rather limited. So far only very few sailors were killed or injured by pirates in the water around Somalia. Compare to the other region of the world it is a main difference between Somali pirates and pirates in the rest of the world.

There is another point, which can be a key element of Somali piracy problem. Sheikh Hassan Dahir Aweys (Somali Islamist leader of Alliance for the Re-Liberation of Somalia) told that "We are calling for the immediate release of all international vessels under the command of Somali pirates, who are undermining international peace and trade". He pointed out that piracy was almost eliminated during the six months in 2006 when the Union of Islamic Court, ruled most of southern and central Somalia. "We are the only force that could eliminate piracy in the Somalia waters, but the world rejected to give us the opportunity to rule Somalia, despite the will of the vast majority of the people of Somalia. If we are given the opportunity to fight piracy and general lawlessness we can do that comfortably. Piracy is part of lawlessness, and during our months of Islamic leadership, pirates were underground (Blackwater in London, Lloyd's List, 3 December 2008)".

Africa Expert at Exclusive Analysis told that "We expect the Islamist groups to increase their internal competition for power, leading to intensified fighting around the capital Mogadishu however piracy attacks launched off the southeastern coast would probably be significantly reduced" (Frank Lloyd's List, 4 December 2008).

But on the other hands it can be even worst solution if we consider the global war with terrorism.

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17.2 The importance of the educational factor to assure the safe and security on the sea

L.C. Stan & N. Buzbuchi
Constanta Maritime University, Constanta, Romania

ABSTRACT: Our paper deals with the methods and techniques used in the educational process in the Maritime University of Constanta to develop the practical abilities and principles in applying the operational procedures and the utilization of the specific safe and rescue equipments at sea, by the students and maritime officers. The educational process has an outstanding role in the career of a maritime officer and the problem of the safety and security is essential in order to avoid catastrophes and for saving human lives. The paper presents the implementation, the role and function of the new simulators as part of the teaching process. Quality cannot be obtained without new teaching methods and training procedures, where IT and simulators occupy an outstanding place. These new methods and techniques have been introduced in the Maritime University of Constanta (MUC) step by step, from the multimedia tools to computers with dedicated complex software.

1 INTRODUCTION

Maritime University of Constanta -MUC has a unique profile in the Romanian higher education, offering its graduates licenses for maritime officer and for engineer too. There are two faculties in the MUC: the Navigation Faculty and the Naval Electromechanical Engineering Faculty.

The University provides additional training for seafarer and ashore personal, many of which are our (MUC) graduates. The MUC provides training and education for students and officer in accordance to the State educational standards, with Maritime Authority requirements and in compliance with the STCW standards.

With the introduction of the International Safety Management (ISM) Code the responsibility of seafarers' competency now also lies with the ship owner. Section 6.5 of the ISM Code states that the ship owner should establish and maintain procedures for assessing competence and identifying any training which may be required in support of the Safety Management System (SMS) and ensure that such training is provided for all personnel concerned.

Over the last decade the world vessel fleets have become highly sophisticated and technically advanced. However, due to human error, disasters still occur. Operational failures a miss-communication can easily cause major accidents or expensive breakdowns with severe economical consequences for a company.

The new challenge for shipping companies, maritime college and training centers will be to find tools for such training and evaluation.

Once the educational system registered a reform, due to the major impact of the technical revolution during the last twenty years, the teaching methods had to undergo major changes.

The faculties provides by the latest achievements of the information technology, not only as regards computing speed and storing capacity, but also, and especially through the unprecedented development of software packages, which offer the possibility of commissioning such resources, imposed themselves in the last years as an essential and outstanding support in the educational process. The new approaches of the training methods include the following: improved links between on-the-job and off-the-jobs activities; self-learning and distance learning training packages (computer, video and audio teaching aids); trainer training; modular training; simulator training.

The main objectives of the new approach for educational methods and techniques are as follows: to make a knowledge transfer from the traditional support; to organize the inter-active data bases for storing, updating and transfer of knowledge to the trainees; to develop some protection, supervising and administration systems for the access to such data bases; to implement the intranet and internet access information systems.

One of principal goal of our maritime educational process is to allow, key problems of fleet such as safe navigation and safety of life at sea. MUC developed a number of educational and training programs for maritime specialists and other personal engaged in use and maintenance of the equipment for safety of navigation.

In this paper, we present some of the main methods and techniques applied in MUC for the continuous training and improvement of officers.

2 TRAINING PROCESS IN MARITIME UNIVERSITY OF CONSTANTA

In the last decade, the educational system in MUC has suffered major transformation, which caused an essential progress in learning and training process. The training process was developed by different periods:

- 1990–1994 – practice training in the university's technical labs (Radiolocation, Electrical navigation equipment, Electrical engines, Internal combustion engines, Naval mechanical, Hydraulically, cooling system, Fluid Mechanics and hydraulic Machines, Naval steams generators and student training on the Neptun school ship;
- 1994–2000 – theoretical training and evaluation control using a network computers and multimedia tools. E-learning is used both in the theoretical and practical process for different purposes: testing, evaluation, self-evaluation, creating virtual laboratories, simulations. Specialized software are used by students according to the different specialties (electro technical, mechanical, navigation). Soft wares for controlling and auto controlling students; knowledge have been done for different moments: initial tests, daily tests, final evaluation tests. Using different tests in different moments of the educational process, this can afford the continuous improvement of students' training level. Audio-video methods, simulation, computer animation proved to be extremely attractive for our students, with good results as both their technical and practical knowledge.

These methods determined the students to be more active using the Internet, for growing their scientific and professional information and in finishing their license.

E-learning is used in MUC for on-line courses, masters' courses and for obtaining the officers' maritime license.

From 2001, it has been applied computer knowledge testing for obtaining the officers' III license.

2004 – future – using the simulator for training and evaluation control. This new choice is the perfect solution for achieving the perfect simulation on board: regarding operating ships, maritime equipments, practicing procedures established by ISM, the main plants and malfunctions by plants and machines.

This paper will be presented the types of controlling tests, also the procedure of testing and evaluation of the graduates.

3 THE SIMULATORS, MEANS OF IMPROVEMENT THE EDUCATIONAL EFFICIENCY FOR SAFE NAVIGATION SAFETY ON THE SEA

Simulator training has over the last years proved to be an effective training method when training engineers, especially where an error of judgment can endanger life, environments and property. A dynamic real-time computerized simulator can, when it comes to certain situations, compress years of experience, into a few weeks and give competence to handle these situations and know ledge of the dynamic and interactive processes typical for a real engine room.

Proper simulator training will reduce accidents; will prevent the maritime disaster and marine pollution too, besides its educational training seamanship in navigation and maneuvering. The simulators improve efficiency, and give the engineers the necessary experience and confidence in their job-situation.

Starting with 2002 year, MUC installed and put in operation three Kongsberg Norcontrol simulators: GMDSS and SAR simulator, Engine room simulator and Navigation simulator. The MUC installed these simulators to organize practical training for its students and graduates, for ship and shore users, as well as for system service engineering training. Simulators, used for the practical training, proved to be the perfect solution to create appropriate conditions similar to the real situation on board ship- regarding operating ships, maritime equipments, practicing procedures established by the International Safety and Rescue Rules.

The use on ship the GMDSS equipment widened its possibilities for safety purposes. The GMDSS simulator includes one GMDSS console equipped with different GMDSS replica instruments.

The equipment of a console consists of the following components:

Radiotelephone VHF simplex/duplex/semi duplex channel
Radiotelephone SSB MF and HF
DSC Controller and receiver MF and HF
Navtex
Inmarsat C complete
Radio telex (NBDP)
EPIRB and Sart

All the ship's GMDSS/SAR radio equipment, SART (Search and Rescue Transponder), EPIRB (Emergency Position Indicating Radio Beacon), Radar display, Navtex, Communication systems (VHF, DSC, NBDP) are graphically simulated on the student PC station.

The GMDSS and SAR simulator is used both, by the students of Navigation Faculty and those of Naval Electromechanically, but with different targets in accordance with their competences on the ship board.

The GMDSS and SAR simulator consists now of a main instructor station and four student stations and it is to be fitted with two more students stations this year. The simulator includes all radio communication equipments for sea area A1 to A4 in accordance with international regulations IMO/SOLAS/GMDSS. The instructor station is connected to the student stations by a computer network. The simulator provides a training interactive package combining computer-based training with PC simulation. The instructor has the possibility of creating a lot of exercises and modifying different parameters, such as: sea area, types

Figure 1. Engine control room.

Figure 2. Main switchboard.

Figure 3. Local Control Room with 4 Local Operating Stations (LOS).

of equipment, ship's geographical position, heading and speed, identification number and name, etc. By means of computer the instructor can configure all the instruments which are available to the student for each SAR-mission exercise.

All the ship's GMDSS/SAR radio equipment, SART (Search and Rescue Transponder), EPIRB (Emergency Position Indicating Radio Beacon), Radar display, NAVTEX communication systems (VHF, DSC, NBDP) are graphically simulated on the student PC station.

In Maritime University of Constanta exists a KONGSBERG NORCONTROL ERS-MC 90-III engine room simulator which has:

1 instructor station;
2 control room equipment;
3 engine room equipment;
4 internal telephone;
5 synthesized sound system;
6 documentation;
7 installation start-up;
8 training.

The concept of training and evaluation control (TEC) is an instructor system which gives the instructor/student a tool for an efficient handling of the training and evaluation of the predefined task and the student an easy operated system. This system is build up of scenarios and all scenarios can be edited and changed on-line, while the simulator is running, or created off-line. The on-line facility is normally used during a session, when the training progress has to be justified. The students run their training from TEC in the operator mode.

In the following pictures, Figures 1–3, are presented the solution of our engine room simulator.

For the training of students of Navigation Faculty was installed a Transas simulator. The Transas full mission bridge configuration consists of the entire spectrum of navigational controls to be expected on a bridge, including radar displays, ECDIS, vessel controls and navigational sensors, all of which are build into consoles. All related visual and sound effects are also incorporated into the simulator to create a realistic, professional simulated environment. Main components of the Full Mission bridge simulator include Conning station, ECDIS display, NavAids and Instrumentation display, Bearing/CCTV/2nd Conning station, Visual channel(s), Real ship controls, Mathematical model, Databases. It will be exemplified the exercises created by the instructors and the mood of evaluation for each type of simulator.

4 CONCLUSIONS

Various simulators and simulations software together with other hands-on training including labs training ship have played an important role in providing and assessing the skills that the students need to acquire. MUC developed a number of educational and training programs for maritime specialists and other personnel engaged in use and maintenance of the equipment for safety of navigation.

Simulators are powerful means in the maritime educational systems as they developed multipurpose skills. They render students the possibility to know the processes in their dynamics and interaction, facilitate an easy and fast understanding of the basic theoretical notions, which can be demonstrated by using programs that initiate different drills that simulate real on-board situations.

As a result of introducing these modern technologies in maritime education, the results are positive and stimulative for pursuing this activity. The students are guided towards independent study and to self evaluation. These methods make learning and training more effective and attractive, and have increased the student's interest in attending the courses, laboratories and simulators. The use of simulators has proved to be not only a modern and fast method of learning and developing practical skills for the future maritime officers, but also very profitable from the economic point of view.

Maritime University of Constanta, and implicitly the Engine Room Simulator, drew and got accredited from the Naval Authority Romania for the courses Engine Team and Resource Management and Bridge Team and Resource Management, courses directed to all the students and maritime officers.

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17.3 Standard for quality assurance: The case of Philippine Maritime College

A.C. Doromal
John B. Lacson Colleges Foundation-Bacolod, Inc., Bacolod City, Philippines

ABSTRACT: Higher education is challenged to be responsive to the current demands of quality education through the translation of knowledge, skills, and attitudes that conform to internationally accepted standards. SCTW '95 mandates that maritime academies should ensure the development of competent manpower for maritime industry. John B. Lacson Foundation Maritime College has articulated adherence and compliance with ISO series of standards for Maritime Academies in the Philippines. This study evaluated the extent of deployment of QSS in eight key areas and its implication to the International Shipping Industry. Findings revealed that JBLFMC has a very high extent of deployment in all areas of QSS that indicates an extensive implementation of its processes, procedures and services. A remarkable implication signifies the global competitiveness of the graduates and an assurance of a world-class workforce trained in the academe with total quality system, committed to meet the challenges of the maritime industry.

1 INTRODUCTION

Seafarers are the core elements of the shipping industry and the demand for skillful and competent seafarers has been growing. Due to the global nature of shipping industry, a necessity for a quality standards geared towards the assurance of attaining the mandated competencies by (STCW Convention '78, '95) has gained due importance.

This research was anchored with Quality Assurance as a philosophy and a process in which all the functions and activities of an institution shall be treated equally, planned, controlled and implemented in a systematic and scientific manner (Venkaiah, 1995:159).

Among the various maritime academies in the Philippines, John B. Lacson Foundation Maritime College is imperative in the attainment of quality assurance, as it indicates a strong workforce in the global shipping market. The JBLMC is recognized as one of the bearers of maritime education and training of excellence in the Philippines and in the world. As an educational institution, it has its quality standards geared toward the quest for excellence.

Guided by the quality policy which is "to comply with national and international standards and strive to exceed stakeholders expectations", the school asserts the full implementation of quality standard system which will lead to the attainment of quality assurance in the education and training of cadets.

Among the various maritime schools in the Philippines, John B. Lacson Foundation Maritime College is imperative to realize the importance of the establishment of a quality management system.

Since, its establishment in 1948 as Maritime Academy, the first in the coastal region of the Visayas and Mindanao, it has turned out competent, disciplined and values-oriented marine deck officers and engineers for both domestic and foreign shipping companies.

In 1997, JBLFMC in its intense propensity to be internationally competitive in maritime education started to seek registration of its Quality Management System (QMS) to the ISO 9000 series of standards/Rules for Maritime Academies and Training Center under a reputable international assessor the Det Noske Veritas (DNV), hence, the school was the first accredited maritime learning institution in the Philippines (Review Journal, 1998).

2 THE PROBLEM

The purpose of this study was to evaluate the extent of deployment of quality standards system of John B. Lacson Foundation Maritime College and establish its implication to the International Shipping Industry.

Specifically, this study sought to answer the following questions:

1 What is the extent of deployment of the Quality Standards System (QSS) by JBLFMC according to the following areas: (1) Mission, Goals and Objectives, (2) Corporate Plans, (3) Organization and Management, (4) Internal Control, (5) Human Resource Administration, (6) Plant and Facilities, (7) Academic Affairs, (8) Accounting and Finance
2 What are the implications of the findings to the Shipping Industry?

2.1 *Theoretical and conceptual framework*

In today's climate of intensely competitive international trade, companies must identify and put into place mechanisms that will facilitate success in world markets. Foremost among such mechanisms is International Organization for Standardization (ISO) certification. ISO has agreed on a set of quality assurance and quality management standards and will certify companies that meet the quality standards worldwide (Anschutz, 1996).

In Malcolm Baldridge National Quality Award, Anthony C. Fletcher (2004), discussed that hundreds of thousands of organizations around the world have pursued the development and registration of their Quality Management System (QMS) to the International Organization for Standardization (ISO) 9000 series of standards with the perception that this is the first step in their pursuit of world-class performance.

In the words of Drystad (1994), by sharing and working together through the total quality systems approach, the schools can improve and provide better learning options to students, thus ensuring a world-class workforce.

The implementation of the Quality Standards System in maritime schools in accordance with the Rules for Quality Standard System is a vital tool in ensuring that all the requirements of the Standards of Training, Certification and Watchkeeping (STCW '78; as amended '95) are complied with, thus assuring that the Filipino Seafarers shall continue to be globally competitive (CHED Memorandum, 1998).

Section 35 of Commission on Higher Education (CHED) Memorandum #51 dated 1997 (Article 13) (Quality Standards System), provides that "Every maritime school shall develop and implement a quality standard system in accordance with the provisions of the policies, standards and guidelines" (CHED Memorandum, 1997).

Moreover, Section 36 of the same memorandum informs that "Recognizing that Filipino seafarers shall be globally competitive in compliance with 1995 amendments to STCW '78 as amended '95 and other international laws and conventions, the school facilities, equipment and teaching competencies shall be upgraded to meet the quality standards.

Owing to the fact that the country's economy depends heavily on seafarers and the quality of seafarers depends on the quality of graduates that the maritime schools produce, the only way of ensuring the quality of graduates in maritime schools, specifically in JBLFMC, is to fully implement the QSS.

The JBLFMC took the lead and got certified in 1997, way ahead of the CHED mandate. JBLFMC was the first in the Philippines and third in the world to get certified under the Det Norske Veritas (DNV) Rules for Maritime Academies (http://jblcfbac.lasaltech.com/jblcf%20system.htm).

It is a guideline providing a systematic structure to assess the quality standards system of John B. Lacson Foundation Maritime College.

The context determines that JBLFMC formulated the Quality Standards System in order to establish quality management system. Included in the context is the Det Norske Veritas and Commission on Higher Education (CHED) that ensures the deployment and compliance with quality standards.

Moreover, Input evaluation which is based in the eight (8) areas of Quality Standards System needs looking into.

Process includes the assessment of the Quality Standards System and the identification of the strengths and weaknesses, which was made the bases for implications to the shipping industry.

3 METHODOLOGY

The participants of this study were the total population of 175 which includes the faculty members and administrative staff of JBLFMC in the Philippines. A descriptive quantitative and qualitative research was employed to conduct this study.

This investigation utilized a modified research instrument adopted from the study of Magramo (2003). It was based on the Quality Standards written in the Quality Management Manual of JBLFMC.

The data-gathering instrument was interpreted by the use of rubrics. Heidi Goodrich (2008) defines rubrics as a scoring tool that lists the criteria and specify the level or extent of performance for several levels of quality.

To determine the extent of deployment of QSS as indicated by the compliance of the respondents, the weighted mean was used, due to the varied number of respondents.

Analysis of documents gathered from management review reflective of internal audit and academic audit, was used as research method.

Moreover, personal observations were conducted by the researcher in several classes, to observe the teacher's teaching and student's learning.

It further looked into the implications of the findings to the shipping industry.

4 RESULTS

On the Extent of Deployment with the QSS in JBLCF according to Eight (8) Areas.

Table 1, demonstrates the extent of deployment of Quality Standards System (QSS) in eight (8) areas in JBLFMC. It is apparent that all eight (8) areas show great extent of deployment as experienced by respondents. Mission, Goals and Objectives, showed the interpretation that 90.94% of the respondents were convinced process and procedures mandated by the Quality Management Manual (QMM) relative to Mission, Goals and Objectives were deployed, thus attaining Very High extent.

Moreover, 94.86% of the respondents indicated that Corporate Plans and Strategies were implemented. Likewise, in Organization and Management, Internal Control, Human Resource Management, Plant and Facilities, Academic Affairs and Accounting/Finance, obtained a corresponding respondents' percentage of 92.65, 92.40, 93.10, 92.50, 97.28 and 100.00

respectively. As a whole, 94.84% of the respondents manifested that JBLFMC is full deployment of its QSS. Consequently the school organization is in full conformity with QSS.

A qualitative analysis is presented hereunder:

The result showed that there was a very high extent of implementation in all areas of the quality standard system, which indicates that a well-integrated and innovative approach is deployed to all functional areas or work units.

4.1 *Vision, mission and objectives*

The appropriate and clearly defined mission, vision and objectives are most important in the college. The school's quality assurance system is articulated through the active integration of teaching, research, extension and engagement, which creates an innovative learning environment that stresses mastery of fundamentals, intellectual, discipline, creativity, problem solving and responsibility. Core values of the college is integrated in the classroom instruction, and the harmonization of school objectives and activities was established. Enhancing its historic strengths in Maritime education, a full commitment to excellence is demonstrated in the academic disciplines that ensure leadership for intellectual, cultural, social, economic and technological development in the nation and the world.

Table 1. Deployment with the QSS in JBLCF on Eight (8) areas.

Areas	Extent of deployment in percentage	Interpretation
Mission, Goals, Objectives	94.90%	Very High
Corporate Plans and Strategies	94.86%	Very High
Organization and Management	92.65%	Very High
Internal Control	92.40%	Very High
Human Resource Management	93.10%	Very High
Plant and Facilities	92.50%	Very High
Academic Affairs	97.28%	Very High
Accounting/Finance	100.00%	Very High
As a Whole	94.84%	Very High

4.2 *Corporate plans*

To ensure a quality plan that addresses the functions and operation of the school, a periodical environmental scanning is conducted through needs assessment, continuous improvement reports, internal and external audit. All concerns are reviewed, analyzed and used as springboard for institutional plan. All personnel were involved in the formulation of development plan, thus, giving sense in the implementation wherein synergy was apparent rather than competition. Coherence in every task was prevailing in the organizational climate. Resistance in the implementation of corporate plan was not remarkable. Institutional plan is anchored with vision, mission and objectives.

4.3 *Organization and management*

Indicating an assurance of the full-commitment of faculty and administrative staff, a total involvement was explicitly demonstrated in quality related activities such as goal setting, planning, implementation and output utilization. This gave a sense of self-worth to every member of the organization, thus, realizing the value of commitment.

Various approaches and strategies were deployed to ensure that employees (faculty and staff) are empowered thru enhancing their competencies and skills in-line with their specialization, thus responsibility and initiative for innovations are evidently articulated.

4.4 *Internal control*

Various departments of the college is interrelatedly functioning following a systemic approach.

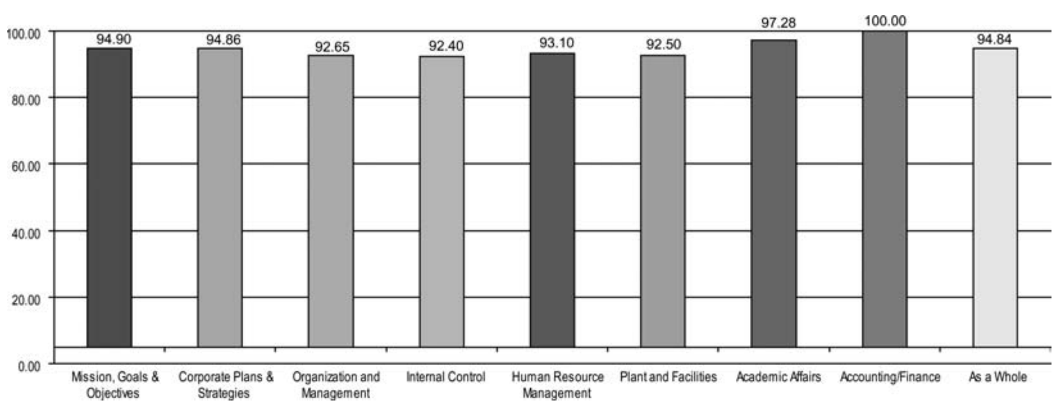

Figure 1. Graphical Presentation on the Extent of Compliance with the QSS in JBLCF on Eight (8) Areas.

Appropriate documentation is strictly observed, to ensure the authenticity of information, activities and other related operations of the school.

Quality assurance of academic programs is done through regular review and assessment of degree programs and instruction and through assessment of the quality of and student access to academic resources and services and student support services that promote student development, retention and graduation. Ensure appropriate and adequate library resources. Effective assessment is vital to quality assurance of higher education. The college has established the center for review and competency assessment (CRCA) and the academic audit office (AAO) that conduct competency based assessment mandated by STCW '95. Results serves as baseline for remediation or intervention.

4.5 *Human resource management*

A sustainable faculty and staff development program is fully deployed to provide the right direction for the professional advancement of the teachers and personnel as pillars of quality instruction. Cognizant to the need of a highly qualified and competent teachers, this program ensures the continuous and wholistic development of the school personnel.

A structured performance evaluation system is conducted to ensure objective feedbacking on work performance. Evaluation system includes, self-evaluation, peer evaluation, students' evaluation, classroom observation and head's evaluation.

A reward system was designed and fully implemented. Deserving employees are recognized thru an exemplary award with an equivalent of cash gift and a promotion with a step increment in salary.

Workforce is enriched through active involvement of all faculty members and school personnel as members of various work committees on accreditation, and other key areas of the college. These allow faculty members and personnel to synergized their efforts along with the school continuous development.

Open communication in a 360° model allows an assurance that all gray areas in the school organization is addressed appropriately.

4.6 *Plant and facilities*

Adequate facilities were provided to ensure a quality delivery of services. Conditions of the work and class environment were checked regularly, making it sure that positive influence on teaching-learning, motivation, satisfaction and performance of people in the school community are readily attained. There is a periodic audit of the classrooms, laboratory areas, toilets, library and other strategic areas, to secure accountability in utilization of these areas.

Quality assurance in the college is the sufficiency of laboratory facilities and equipment and its compliance to safety and contingency measures.

Ratio and proportion and functionality of required facilities is fully complied with, as Certified by Technical Working Group of the Commission on Higher Education (CHED). Regular orientation on safety measures is conducted among the users of these facilities. Buildings and other physical structures were in full-compliance with the government regulatory standard, strictly implemented by the City Engineer's Office.

4.7 *Academic affairs*

Quality assurance in JBLFMC was evident in the following features:

Firstly, the academic curricular programs include courses that are systematically sequenced and designed to meet the needs of diverse sectors in the maritime industry. They are in accordance with the enriched competency-based curriculum as per IMO and government guidelines. The curriculum provides a balance between academic excellence (with emphases on science, mathematics and English) and applied skills.

Secondly, highly qualified and competent instructors were maintained by the college. Professional upgrading in-line of specialization was a compulsory task among the instructors.

Thirdly, Quality instruction was articulated in the Instructor's Guide based on higher order thinking skills and indicated through administering a valid and reliable test instrument. The use of instructors guide was an assurance that the main content of the subject were thoroughly covered.

Finally, documents showed that record in the marine and deck licensure examination provided by the Professional Regulation Commission (PRC) had a remarkable increase over the years.

Employment opportunities and scholarship grants was continuously increasing, due to the strong linkages of the school to shipping companies. These are indications for cycle of improvement in the academic training of the students who became competent graduates.

By maintaining the academic standards on admission and retention of students, the college is assured that the status and reputation of the academic training of the students, was indeed a benchmark for national and international qualification in the shipping industry.

4.8 *Accounting and finance*

Governed by thrust of the finance office, internal and external control was strictly deployed, inorder to attain the 100% stability in the financial status that will support the whole operation of the college.

A triangular financial audit reviews are conducted periodically to assess the financial operations of the school: (1) audit conducted by the Accounting Office; (2) verification of the school internal auditor; and (3) external audit by a private auditing firm.

Table 2. On Implications for the Shipping Industry.

Areas	Interpretation	Strength	Implications
Mission, Goals, Objectives	Very High	Persistent monitoring of graduates in their performance onboard and PRC board exam.	An assurance that competence onboardship and qualification is the main thrust of the school
Corporate Plans Strategies	Very High	Members of the school organization keep abreast of the school policy.	National and international standards in the shipping industry are readily complied.
Organization and Management	Very High	Dynamic in the implementation, empowerment and innovations of Quality Policy.	Product realization is of high regard.
Internal Control	Very High	Documentation is strictly observed.	Quality Education and training of cadets as mandated by STCW 1978 as amended in 1995 is guaranteed.
Human Resource Administration	Very High	Competent and qualified instruction in both General Education and Professional subjects is ensured through Faculty Development Program and Shipboard upgrading.	Transfer of technology from the ship to the academe is a continuous process, thus updates for required competencies is attained.
Plant and Facilities	Very High	Adequate laboratory facilities/ simulator is fully complied with.	Technical trainings are extensively delivered.
Academic Affairs	Very High	Curriculum is in full compliance with national and international standards.	Setting the readiness of cadets in competencies as requisites on-boardship through learning experiences provided by curriculum.
Accounting/ Finance	Very High	Provides sense of security for financial logistics	Support system is continuously implemented.
As a whole	Very High	JBLCF is in full compliance with its Quality Standards System (QSS).	Compliance with STCW '78 as amended in '95 Registration of QMS to the ISO 9000.

4.9 *Beyond the college*

Besides the college endeavor on assurance of quality of teaching and government and the industry also play important roles.

As a formal educational institution, the JBLFMC is governed by government laws, policies, rules and regulations as well as the requirement of international and evaluating groups of organizations in the industry. This has brought beneficial results to the institution as an accredited and ISO certified maritime school.

4.10 Conclusion

The success of quality assurance in an organization depends on the total commitment of the management and all the members of its staff. Quality Assurance practices are important for the future existence of Maritime Education providers. Quality assurance practices are here to say especially in the fierce competition faced in the international shipping industry. In order to compete in the 21st century, maritime education providers must examine their quality assurance measures and conduct studies on ways to improve it, inorder to cope with the demand of the shipping industry. Continuous improvement, which is the key to the quest for excellence should be adopted. An approach of full deployment of standards, may serve to provide evidence that an institution has soundly grounded approach to the assurance of quality (Yorke, 1999). Quality assurance is possible through commitment and synergism of the management and all the staff of an institution.

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17.4
Novelties in the development of the qualification standards for electro-technical officers under STCW convention requirements

J. Wyszkowski, J. Mindykowski & R. Wawruch
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: Paper presents prepared by Bulgaria, France, Islamic Republic of Iran, IFSMA, ITF, Malaysia, Poland, Ukraine and the United Kingdom proposal of amendments [1] to the STCW Convention and its Code part A and B [2] establishing international qualification standard for electro-technical officers. It is proposed that the certificates of competency for electro-technical officer and senior electro-technical officers shall be placed in Chapter III "Engine Department" of the STCW Convention, under new Regulations III/6, III/7 and new sections A-III/6, A-III/7 and B-III/6, B-III/7 of the STCW Code. This amended concept it is a logical continuation and further development of the paper [3] which concerned the same issue and was presented at the MarCon 2008 proceedings.

1 INTRODUCTION

Due to the continuous technological development as well as new required qualifications and skills for maintenance of electrical/electronic systems, equipment and installations, there is a significant increase in application for properly qualified electric officers. At the moment, such people are being employed especially on cruise vessels, large ferries and all kinds of special purpose vessels, though their qualifications and competence have not been standardised on the international level [4] It is worth to note the rapid progress in marine electrical and electronic technology, including among others, main electrical propulsion and high voltage systems. The latter solutions are generally accepted in cruise ships construction, it means in the shipbuilding branch which is developed very quickly. This trend may be illustrated by the data published in Cruise Industry News Quarterly [5], dealing with building of 49 new passenger ships for a bill of 25,8 billion US dollars in the years 2008–2012. Those contracts are not only a technological challenge, but first of all, a new impact to develop the electro-technical officers labour market. No doubt that they should be, a highly qualified staff, appropriately prepared to undertake the tasks, duties and responsibilities corresponding to up-to-date technological challenges. In this context it is worthy to mention an opinion expressed in the paper titled "Are engineers getting the electrical training they need?" [4], where it was described frequently met in practice situation: "None of the senior engineers onboard had theoretical or practical education in 6,6 kV generation, distribution, and trouble shooting [4]. To avoid those situations and their dangerous and cost consequences, a new approach concerning the necessity to establish and put into force the qualification standards for electro-technical officers seems to be obvious [1]. Facts and statistics show that such qualified people are indispensable to work on large vessels. Over 2200 of them have been trained in Poland. It is significant that majority of them work under other than Polish flag. Hence, in the event of accident there is a question of a legal responsibility of such qualified people, whose professional qualifications were achieved in Poland and are recognised on Polish territory only. Therefore there is a need for an international qualification standard for electro-technical officers. It is proposed that the certificate of competency for electro-technical officers shall be placed in Chapter III "Engine Department" of the STCW Convention, under new Regulations III/6, III/7 and new sections A-III/6, A-III/7 and B-III/6, B-III/7 of the STCW Code. Paper presents qualification and competency standards for Electro-Technical Officers (ETO) and Senior Electro-Technical Officers (SETO) developed by Bulgaria, France, Islamic Republic of Iran, IFSMA, ITF, Malaysia, Poland, Ukraine and the United Kingdom during *ad hoc* intersessional meeting of the STW working group relating to the comprehensive review of the STCW Convention and Code in order to present during nearest 40th session of the IMO Sub-Committee on Standards of Training and Watchkeeping – STW.

2 PROPOSED CHANGES TO THE STCW CONVENTION

Co-authors suggest to insert in the STCW Convention [1]:

1. In Regulation I/1 paragraph 31, the following new definition (STW 40/7/4): *Electro-technical officer* means an officer qualified in accordance with the provisions of chapter III of the convention;

2. In Regulation I/1 paragraph 32, the following new definition (STW 40/7/4): *Senior electro-technical officer* means an officer qualified for the operation, maintenance and repairs of electrical, electronic, computer systems and equipment, including electrical propulsion;
3. The following new Regulation III/6 – "*Mandatory minimum requirements for certification of electro-technical officer*" (STW 40/7/6):
   1. Every electro-technical officer serving on a seagoing ship powered by main propulsion machinery of 750 kW propulsion power or more, shall hold an appropriate certificate.
   2. Every candidate for certification shall:
      1. be not less than 18 years of age;
      2. have completed not less than 12 months combined workshop skills training and seagoing service of which not less than 6 months will be sea going service as part of an approved training which meets the requirements of section A-III/6 of the STCW Code and is documented in an approved training record book, or otherwise not less than 36 months combined workshop skills training and seagoing service of which not less than 30 months will be sea going service in engine department; and
      3. have completed approved education and training and meet the standards of competence specified in section A-III/6 of the STCW Code.
   3. Every Party shall compare the standards of competence which it required of electro-technical officers for certificates issued before [date] with those specified for the certificate in section A-III/6 of the STCW Code, and shall determine the need for requiring those personnel to update their qualifications.
   4. Seafarers may be considered by the Administration to have met the requirements of this regulation if they have served in relevant capacity on board seagoing ship powered by main propulsion machinery of 750 kW propulsion power or more for a period of not less than 12 months within the last 60 months and meet the competence specified in section A-III/6 of the STCW Code.
4. The following new Regulation III/6 – "*Mandatory minimum requirements for certification of senior electro-technical officer*" (STW 40/7/6):
   1. Every senior electro-technical officer serving on a seagoing ship powered by main propulsion machinery of more than 750 kW propulsion power shall hold an appropriate certificate.
   2. Every candidate for certification shall:
      1. meet the requirements for certification as electro-technical officer and shall have not less than 12 months approved seagoing service as electro-technical officer whilst holding electro-technical officer certificate;
      2. have completed approved education and training and meet the standard of competence specified in section A-III/7 of the STCW code.
   3. Every Party shall compare the standards of competence which it required of senior electro-technical officers for certificates issued before [date] with those specified for the certificate in section A-III/7 of the STCW Code, and shall determine the need for requiring those personnel to update their qualifications.

      Seafarers may be considered by the Administration to have met the requirements of this regulation if they have served in relevant capacity on board seagoing ship powered by main propulsion machinery of 750 kW propulsion power or more for a period of not less than 12 months within the last 60 months and meet the competence specified in section A-III/7 of the STCW Code.

3 SUGGESTED AMENDMENTS TO THE CODES

A new sections A-III/6 "*Mandatory minimum requirements for certification of electro-technical officer*" and B-III/6 "*Guidance regarding – the training and certification for electro-technical officers*" shall be inserted after sections A-III/5 and B-III/5. The new section A-III/6 shall contain following requirements for on-board training and standard of competence for ETO [1]:

Training

1. The education and training required by paragraph 2.3 of regulation III/6 shall include training in electronic and electrical workshop skills relevant to the duties of electro-technical officer.

Onboard training

2. Every candidate for certification as electro-technical officer shall follow an approved program of onboard training which:
   1. ensures that during required period of seagoing service the candidate receives systematic practical training and experience in the tasks, duties and responsibilities of an electro-technical officer;
   2. is closely supervised and monitored by qualified and certificated officers aboard the ships in which the approved seagoing service is performed; and
   3. is adequately documented in training record book.

Standard of competence

3. Every candidate for certification as electro-technical officer shall be required to demonstrate ability to undertake the tasks, duties and responsibilities listed in column 1 of table A-III/6.

Table A-III/6. Specification of minimum standards of competency for ETO [1].

Column 1	Column 2	Column 3	Column 4
Competence	Knowledge, understanding and proficiency	Methods for demonstrating competence	Criteria for evaluating competence
Function: electrical, electronic and control engineering at operational level			
Monitor the operation of electrical, electronic and control systems	Basic understanding of the operation of mechanical engineering systems including: 1. Prime movers including main propulsion plant 2. Engine room auxiliary machineries 3. Steering systems 4. Cargo handling systems 5. Deck machineries 6. Hotel systems Basic knowledge of heat transmission, mechanics and hydromechanics *Knowledge of:* Electro-technology and electrical machines theory Fundamentals of electronics and power electronics Electrical power distribution boards and electrical equipment Fundamentals of automation, automatic control systems and technology Instrumentation, alarm and monitoring systems Electrical drives Technology of electrical materials Electro-hydraulic and electro-pneumatic control systems Appreciation of the hazards and precautions required for the operation of power systems above 1000 Volts	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate 4. approved laboratory equipment training	Operation of equipment and system is in accordance with operating manuals Performance levels are in accordance with technical specifications
Monitor the operation of Automatic control systems of propulsion and auxiliary machinery	Preparation of control systems of propulsion and auxiliary machinery for operation	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate 4. approved laboratory equipment training	Surveillance of main propulsion plant and auxiliary systems is sufficient to maintain safe operation condition

(*Continued*)

Table A-III/6. Continued

Column 1	Column 2	Column 3	Column 4
Competence	Knowledge, understanding and proficiency	Methods for demonstrating competence	Criteria for evaluating competence
Operate generators	Coupling, load sharing and changing over generators	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate 4. approved laboratory equipment training	Operations are planned and carried out in accordance with established rules and procedures to ensure safety of operations
Operate computers and computer networks on ships	Understanding of: 1. main features of data processing 2. construction and use of computer networks on ships 3. bridge based, engine room based and commercial computer use	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate 4. approved laboratory equipment training	Computer networks and computers are correctly checked and handled
Use hand tools, electrical and electronic measurement equipment for fault finding, maintenance and repair operations	Safety requirements for working on shipboard electrical systems. Knowledge of the causes of electric shock and precautions to be observed to prevent shock. Construction and operational characteristics of shipboard AC and DC systems and equipment Construction and operation of electrical test and measuring equipment Application of safe working practices	Assessment of evidence obtained from one or more of the following: 1. approved workshop skills training 2. approved practical experience and tests	Implementation of safety procedures is satisfactory Recognizes and reports electrical hazards and unsafe equipment Selection and use of test equipment is appropriate and interpretation of results is accurate Selection of procedures for the conduct of repair and maintenance is in accordance with manuals and good practice Commissioning and performance testing of equipment and systems brought back to service after repair is in accordance with manuals and good practice
Use English in written and oral form	Adequate knowledge of the English language to enable the officer to use engineering publications and to perform the officer's duties	Examination and assessment of evidence obtained from practical instructions	English language publications relevant to the officer's duties are correctly interpreted Communications are clear and understood

(*Continued*)

Function: Maintenance and repair at operational level			
Maintain and repair automation and control systems of main propulsion and auxiliary machinery	Appropriate electrical and mechanical knowledge and skills *Safety and emergency procedures* Safe isolation of equipment and associated systems required before personnel are permitted to work on such plant or equipment Practical knowledge for the test, maintenance, fault finding and repair Test, detect faults and maintain and restore electrical and electronic control equipment to operating condition Knowledge of the principles and maintenance procedures of navigation equipment, internal and external communication system. *Theoretical knowledge:* Electrical and electronic systems operating in flammable areas *Practical knowledge:* Carrying out safe maintenance and repair procedures Detection of machinery malfunction, location of faults and action to prevent damage	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate 4. approved laboratory equipment training	The effect of malfunctions on associated plant and systems is accurately identified, ship's technical drawings are correctly interpreted, measuring and calibrating instruments are correctly used and actions taken are justified Isolation, dismantling and reassembly of plant and equipment is in accordance with manufacturers safety guidelines and shipboard instructions and legislative and safety specifications. Action taken leads to the restoration of automation and control systems by the method most suitable and appropriate to the prevailing circumstances and conditions
Maintain and repair bridge navigation equipment and ship communication systems			The effect of malfunctions on associated plant and systems is accurately identified, ship's technical drawings are correctly interpreted, measuring and calibrating instruments are correctly used and actions taken are justified Isolation, dismantling and reassembly of plant and equipment is in accordance with manufacturers safety guidelines and shipboard instructions, legislative and safety specifications. Action taken leads to the restoration of bridge navigation equipment and ship communication systems by the method most suitable and appropriate to the prevailing circumstances and conditions

(*Continued*)

Table A-III/6. Continued

Column 1	Column 2	Column 3	Column 4
Competence	Knowledge, understanding and proficiency	Methods for demonstrating competence	Criteria for evaluating competence
Maintain and repair electrical, electronic and control systems of deck machinery and cargo handling equipment			The effect of malfunctions on associated plant and systems is accurately identified, ship's technical drawings are correctly interpreted, measuring and calibrating instruments are correctly used and actions taken are justified Isolation, dismantling and reassembly of plant and equipment is in accordance with manufacturers safety guidelines and shipboard instructions, legislative and safety specifications. Action taken leads to the restoration of deck machinery and cargo handling equipment by the method most suitable and appropriate to the prevailing circumstances and conditions
Maintain and repair control and safety systems of hotel equipment			The effect of malfunctions on associated plant and systems is accurately identified, ship's technical drawings are correctly interpreted, measuring and calibrating instruments are correctly used and actions taken are justified Isolation, dismantling and reassembly of plant and equipment is in accordance with manufacturers safety guidelines and shipboard instructions, legislative and safety specifications. Action taken leads to the restoration of control and safety systems of hotel equipment by the method most suitable and appropriate to the prevailing circumstances and conditions
Function: Controlling the operation of the ship and care for persons on board at operational level			
Organize and manager subordinate crew	A knowledge of personnel management, organization and training on board ships A knowledge of international maritime conventions and recommendations, and related national legislation	Examination and assessment of evidence obtained from approved in service training and experience	The crew are allocated duties and informed of expected standards of work and behaviour in a manner appropriate to the individuals concerned Training objectives and activities are based on an assessment of current competence and capabilities and operational requirements

(*Continued*)

Ensure compliance with pollution prevention requirements	*Prevention of pollution of the marine environment* Knowledge of the precautions to be taken to prevent pollution of the marine environment Anti-pollution procedures and all associated equipment	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience	Procedures for monitoring shipboard operations and ensuring compliance with MARPOL requirements are fully observed
Prevent, control and fight fire on board	*Fire prevention and fire-fighting appliances* Knowledge of fire prevention Ability to organize fire drills Knowledge of fire-fighting systems Action to be taken in the event of fire, including fires involving oil systems	Assessment of evidence obtained from approved fire-fighting training and experience as set out in section A-VI/3	The type and scale of the problem is promptly identified and initial actions conform with the emergency procedure and contingency plans for the ship Evacuation, emergency shutdown and isolation procedures are appropriate to the nature of the emergency and are implemented promptly The order of priority, and the levels and time-scales of making reports and informing personnel on board, are relevant to the nature of the emergency and reflect the urgency of the problem
Operate life-saving appliance	Ability to organize abandon ship drills and knowledge of the operation of survival craft and rescue boats, their launching appliances and arrangements, and their equipment, including radio life-saving appliances, satellite EPIRBs, SARTs, immersion suits and thermal protective aids. Knowledge of survival at sea techniques	Assessment of evidence obtained from approved training and experience as set out in section A-VI/2, paragraphs 1 to 4	Actions in responding to abandon ship and survival situations are appropriate to the prevailing circumstances and conditions and comply with accepted safety practices and standards
Apply medical first aid on board ship	Practical application of medical guides and advice by radio, including the ability to take effective action based on such knowledge in the case of accidents or illnesses that are likely to occur on board ship	Assessment of evidence obtained from approved training as set out in section A-VI/4, paragraphs 1 to 3	Identification of probable cause, nature and extent of injuries or conditions is prompt and treatment minimizes immediate threat to life

(*Continued*)

Table A-III/7. Specification of minimum standards of competency for SETO [1].

Column 1	Column 2	Column 3	Column 4
Competence	Knowledge, understanding and proficiency	Methods for demonstrating competence	Criteria for evaluating competence
Function: electrical, electronic and control engineering at operational level			
Monitor and evaluate electrical power generation and consumption	*Expanded theoretical knowledge* Electro-technology and electrical machines theory Electronics and power electronics Electrical power distribution boards and electrical equipment Automation, control systems and instrumentation	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate	The methods of measuring the load capacity of the generators and motors are in accordance with technical specifications Performance levels are in accordance with technical specifications
Maintain safety of equipment, systems and services	*Practical knowledge* Operation and maintenance of: 1. Electrical generation and distribution systems 2. Electrical propulsion plant 3. Auxiliary machinery, including pumping, auxiliary boiler plant and steering-gear control systems 4. Integrated control systems 5. Electrically operated cargo-handling equipment and deck machinery		Safety of equipment, systems and services is in accordance with manufacturers safety guidelines and shipboard instructions, legislative and safety specifications.
Diagnose faults, maintain and restore electrical power, electronic and control equipment to operating condition	Understand and diagnose the underlaying cause of malfunctions in electrical power, electronic and control systems and equipment	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate 4. approved laboratory equipment training	Maintenance activities are correctly planned in accordance with technical, legislative, safety and procedural specifications The effect of malfunctions on associated plant and systems is accurately identified, ship's technical drawings are correctly interpreted, measuring and calibrating instruments are correctly used and actions taken are justified
Diagnose faults, maintain and restore navigation and communication equipment to operating condition	Understand and diagnose the underlaying cause of malfunctions in navigation and communication systems and equipment	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate	The methods of comparing actual operating conditions are in accordance with recommended practices and procedures Actions and decisions are in accordance with recommended operating specifications and limitations

(*Continued*)

Operate, maintain and manage power systems in excess of 1000 Volts	*Theoretical knowledge:* High voltage technology Safety precautions and procedures Electrical propulsion of the ships, electrical motors and control systems *Practical knowledge:* Safe operation and maintenance of high voltage systems including knowledge of the special technical type of high voltage systems and the danger resulting from operational voltage of more than 1000 V	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate 4. approved laboratory equipment training	Operations are planned and carried out in accordance with established rules and procedures to ensure safety of operations
Function: controlling the operation of the ship and care for persons on board at the management level			
Plan and schedule operations	*Knowledge of:* 1. computer-based management systems of periodical maintenance and repairs 2. preparations for dry docking and shipyard repairs and maintenance 3. class requirements	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate	The planning and preparation of operations is suited to the design parameters of the power installation and to the requirements of the voyage
Monitor and control compliance with legislative requirements and measures relating to electrical and electronic equipment and systems to ensure safety of life at sea and protection of the marine environment	Knowledge of relevant international maritime law embodied in international agreements and conventions Regard shall be paid especially to the following subjects: 1. certificates and other documents required to be carried on board ships by international conventions, how they may be obtained and the period of their legal validity 2. responsibilities under the relevant requirements of the International Convention for the Safety of Life at Sea 3. responsibilities under the International Convention for the Prevention of Pollution from Ships 4. maritime declarations of health and the requirements of the International Health Regulations 5. responsibilities under international instruments affecting the safety of the ships, passengers, crew or cargo 6. methods and aids to prevent pollution of the environment by ships 7. knowledge of national legislation for implementing international agreements and conventions	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate	Procedures for monitoring operations and maintenance comply with legislative requirements Potential non-compliance is promptly and fully identified Requirements for renewal and extension of certificates ensure continued validity of survey items and equipment

4. The minimum knowledge, understanding and proficiency required for certification is listed in column 2 of table A-III/6 and it shall take into account the guidance given in part B of this Code.
5. Every candidate for certification shall be required to provide evidence of having achieved the required standard of competence tabulated in columns 3 and 4 of table A-III/6.

In new Section B-III/6 shall be inserted the following recommendations:

In addition to the requirements stated in table A-III/6 of this Code, Parties are encouraged to take into account resolution A.702(17) concerning radio maintenance guidelines for the global maritime distress and safety system within their training programmes.

A new section A-III/7 "*Mandatory minimum requirements for certification of senior electro-technical officer*" shall be inserted after sections A-III/6. The new section A-III/7 shall contain following requirements for on-board training and standard of competence for SETO:

Standard of competence

1. Every candidate for certification as senior electro-technical officer of seagoing ships powered by main propulsion machinery of more than 750 kW shall be required to demonstrate ability to undertake the tasks, duties and responsibilities listed in column 1 of table A-III/7.
2. The minimum knowledge, understanding and proficiency required for certification is listed in column 2 of table A-III/7. This incorporates, expands and extends in depth the subjects listed in column 2 of the table A-III/6 for electro-technical officer.
3. Training and experience to achieve the necessary level of theoretical knowledge, understanding and proficiency shall take into account the relevant requirements of this part.
4. Every candidate for certification shall be required to provide evidence of having achieved the required standard of competence in accordance with the methods for demonstrating competence and the criteria for evaluating competence tabulated in columns 3 and 4 of table A-III/7.

4 MINIMUM STANDARD OF COMPETENCY FOR ETO AND SETO

Table A-III/6 presents the specification of minimum standards of competence for electro-technical officers.

Table A-III/7 presents the specification of minimum standards of competence for senior electro-technical officers.

5 FINAL REMARKS

Proposal of amendments to the STCW Convention and its Code establishing international qualification standards for electro-technical officers described in this paper was a result of the Intersessional Working Group meeting in September 2008, next presented during the 40th session of the IMO STW Sub-Committee, regarding the comprehensive review of the STCW Convention and Code, scheduled from 02 to 06 February 2009.

In the meantime, between the Intersessional Working Group meeting on the STW issues some new documents related to the discussed matter appeared, like STW 40/7/54 submitted by Japan, STW 40/7/56 submitted by Denmark and STW 40/7/17 submitted by Germany.

Finally, three options for further considerations are at the table: the first one concerning two-level electro-technical officers standards, including ETO and SETO levels, the second option presented by the Germany, supported by USA, consisting of two-level electric / electronic staff understood as electro-technical officer and able seafarer electro-engineering, and the third option - all electric / electronic duties belong to and are realized by marine engineers (Denmark and Japan). The further steps of the procedure will be oriented for looking for the best solution and compromise proposal possible to accept by the majority of IMO member states.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

17.5
Assessment of ISPS code compliance at ports using cognitive maps

M. Celik & Y. Ilker Topcu
Istanbul Technical University, Istanbul, Turkey

ABSTRACT: International ship and port facility security (ISPS) Code was developed by the International Maritime Organization (IMO) as an execution framework to ensure high level of security measures applicable to ships and port facilities. Besides contributions of ISPS Code towards security improvement, additional bureaucracy (i.e. documentation, certification, training, expenses etc.) and serious shortfalls have appeared during implementation process. This paper explores the ISPS Code practice at ports based on cognitive mapping approach. The outcomes of this research can be proposed to international maritime authorities in order to enhance the existing concept and regulatory compliances of the ISPS Code in respect to industrial feedback.

1 INTRODUCTION

Security in maritime transportation is one of the focal issues of maritime interests. This dilemma requires setting critical measures and initiatives, which should effectively be designed and implemented. In this case, the consequences of security improvements are also beneficial to service quality and business performance in international shipping (Thai, 2007).

To provide a standardized framework for implementing security precautions and to control the potential risks for ships and port facilities, practicing of an international ship and port facility security (ISPS) code was initiated by the International Maritime Organization (IMO) (Hesse & Charalambous, 2004; King, 2005). The ISPS code establishes cooperation between government agencies and the shipping and port industries in perception of security threats and preventing security incidents affecting ships in ports (Mensah, 2004). The implementation of the ISPS code necessitates following well-designed procedures to capture most of the probable risky situations in a quick response. Thus, it requires both flexible and consistent plans to overcome all those unexpected circumstances (Tzannatos, 2003).

The aim of this paper is to delineate the current implementation procedure of the ISPS Code at container terminals. Specifically, cognitive mapping approach is utilized to model the industrial feedbacks about the shortcomings of the ISPS Code. Consequently, a simple representation of the raised problems in ISPS Code practice is graphically demonstrated.

2 COGNITIVE MAPS

2.1 *Cognitive mapping*

Cognitive mapping is the task of delineation a person's thinking about a problem or issue. Initially, Tolman (1948) introduced the fundamental principles, which have been referred as guidelines for cognitive psychology research. A cognitive map approach ensures participations of the decision makers' motivation through creative decision-making. In addition, it is an active tool, which allows modification of dynamic attributes in problem environment in accordance with the prior settings and goal.

The structure of a cognitive map mainly captures causal dependencies (Srinivas & Shekar, 1997), thereto; it also provides a graphical representation of different problem cases (Axelrod, 1976; Eden, 1990). In problem construction stage, a node represents the concepts while a number of arcs schematize existing directional relationships among these nodes. Symbolical representation of links is settled using a unidirectional arrow. A statement at the tail of an arrow is taken to cause, or influence, the statement at the arrowhead. According to the casual relation type among concepts (represented by nodes), a minus/plus sign is located on the arrows.

Since it provides satisfactory solutions to many case studies, cognitive maps have been applied several eras in literature (Kitchin & Freundschuh, 2000).

2.2 *Linking up with ISPS Code practice at Ports*

The previous subchapter was intended to provide an introduction to cognitive mapping. Whereupon, it is an onerous task to comply a decision analysis model with serious shortfalls in ISPS Code implementations. In detailed model construction, the mostly encountered problems regarding with regulatory compliances of ISPS Code requirements onboard ships are represented via nodes. The decision analysis aims at achieving two points: (1) Clarifying the casual relations and effects among shortfalls from ship operators' perspective, (2) Formulating further strategies to revise ISPS Code.

Table 1. Mandatory requirements of ISPS Code.

Requirements	
Section 1	General
1.1	Introduction
1.2	Objectives
1.3	Functional requirements
Section 2	Definitions
Section 3	Application
Section 4	Responsibilities of Contracting Governments
Section 5	Declaration of Security
Section 6	Obligations of the Company
Section 7	Ship Security
Section 8	Ship Security Assessment (SSA)
Section 9	Ship Security Plan (SSP)
Section 10	Records
Section 11	Company Security Officer (CSO)
Section 12	Ship Security Officer (SSO)
Section 13	Training, Drills and Exercises on Ship Security
Section 14	Port Facility Security
Section 15	Port Facility Security Assessment
Section 16	Port Facility Security Plan
Section 17	Port Facility Security Officer
Section 18	Training and Drills on Port Facility Security
Section 19	Verification and Certification
19.1	Verifications
19.2	Issue or endorsement of certificate
19.3	Duration and validity of certificate
19.4	Interim certification

3 PROPOSED APPROACH

3.1 *ISPS Code*

The ISPS Code consists of two parts. Part A is mandatory. It contains detailed security related requirements for governments, port authorities, and shipping companies. Part B contains a serious of guidelines about how to meet these requirements. Furthermore, the conference adopted a number of resolutions, in order to facilitate the implementation and the application of those security measures to ships and port facilities. Table 1 outlines the mandatory requirements of the ISPS Code.

3.2 *Feedbacks from Maritime Industry*

Industrial feedbacks and technical reports on ISPS Code-related concerns affecting ships are essential to identify and address the probable problems, which may arise. At this insight, the common idea focuses on excessive pressure of expectations regarding with the ISPS Code. Sometimes, those limitations create some trading disadvantages and operational constraints for merchant ships. Especially, the following items are highlighted about security related matters, which affect the operations of merchant ships (ICS, 2008):

- Additional information demands from port state inspector such as security plan, disclosure, etc.
- Availability of ongoing problems in respect of the continuous synopsis record, records of training, and drills.
- Excessive attitudes of port state control (PSC) officers such as use/display of firearms, crew interrogation, aggressive attitudes, placing armed guards, refusal of access to shore facilities/shore leave.
- Maritime security (MARSEC) level incompatibility between ship and port facility.
- Problems over agreement on a declaration of security.
- Excessive information demands before entering port, current and historical information (e.g. port, customs, and immigration).
- Problems caused by trading history (previous calls at non-compliant port facilities, previous ownership or flag).
- Limitations on access control issues such as identification (requested/provided), manning access points, searching visitors, accompanying visitors, securing waterside access, access to ships for essential visitors.
- Establishment of restricted areas on board and ashore and securing access to them (e.g. bridge, engine room, accommodation).
- Monitoring of deck patrols, landward and seaward monitoring.
- Use of additional security equipments such as automatic identification system (AIS) and ship security alert system.
- Considering security measures for storing of any delivered spares and provisions.
- Additional supervision requirements and integrity in cargo related operations.
- Commercial consequences of delay, detention, refusal of entry or departure, and additional inspections.
- Time constraints to correct the perceived ship security deficiencies.

3.3 *Cognitive map construction on shortfalls of ISPS Code implementation*

Following the industrial feedbacks, representation of the implementation shortfalls of the ISM Code based on a cognitive map structure is constructed in respect to the following dimensions: (i) Goal, (ii) Variables, (iii) Casual relationships among the variables. The goal is predefined as “How can we achieve the regulatory compliances of the ISPS Code in respect to industrial feedback?” On the other hand, the variables, which include both shortfalls and key implementation items of ISPS Code, are given as follows:

V_1: Additional information demand
V_2: Excessive workload onboard
V_3: Immigration bureaucracy
V_4: Port custom facilities
V_5: Security plan
V_6: Drill and training records
V_7: Use of security equipment

Table 2. Square matrix of concepts.

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}	V_{17}
V_1	0	+	0	0	0	0	0	0	0	0	0	0	+	0	0	+	0
V_2	0	0	0	0	-	0	0	0	0	0	0	0	+	0	0	0	0
V_3	+	0	0	0	0	0	0	0	0	0	0	+	0	0	0	+	0
V_4	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0
V_5	+	+	0	0	0	+	0	+	+	+	+	0	0	0	0	+	0
V_6	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V_7	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	+
V_8	0	+	0	0	0	0	0	0	+	+	+	0	+	0	0	+	0
V_9	0	+	0	0	0	0	0	+	0	0	0	0	0	0	0	+	0
V_{10}	+	+	0	0	0	0	0	-	-	0	-	0	+	0	0	+	0
V_{11}	0	+	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0
V_{12}	0	0	0	+	0	0	0	0	0	0	0	0	+	0	+	0	0
V_{13}	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	+	0
V_{14}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V_{15}	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	+	0
V_{16}	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0
V_{17}	+	0	+	-	-	0	0	0	0	-	0	+	+	0	+	+	0

V_8: Manning of access points
V_9: Securing waterside access
V_{10}: Essential visitors' control
V_{11}: Securing restricted areas
V_{12}: Excessive attitudes of PSC officers
V_{13}: Crew fatigue and stress
V_{14}: Commercial consequences of detentions
V_{15}: Refusal of entry or departure
V_{16}: Time constraints at port period
V_{17}: MARSEC level incompatibility

It is the next issue to define existing casual relationships in three different forms:

(i) Positive (+)
(ii) Negative (−)
(iii) No relationships (0)

At this insight, the casual relationships among the variables can be beneficial to formulate enhancement strategies through ISPS Code implementation at ports. Those strategies might include an integrated action plan, combined execution of excessive procedures based on a unique scheme, elimination of unnecessary issues, and other countermeasures. Table 2 addressed the construction of a square matrix including all concepts related to ISPS Code implementation.

Furthermore, in Figure 1 schematizes the focused problem in accordance with the cognitive mapping principals. Broadly, two kinds of concept are defined: implementation shortfalls (V_1, V_2, V_3, V_{12}, V_{13}, V_{14}, V_{15}, V_{16}, V_{17}) and regular items (V_4, V_5, V_6, V_7, V_8, V_9, V_{10}, V_{11}). The blue lines show the positive casual relation (+) while the lines with red colour indicate the negative casual relation (−).

It is the final stage of this approach to transform those relations into useful information to enhance ISPS Code implementation. In this progress, all the negative effects against routine implementation items, in addition, positive relations that increase the degree of implementation shortfalls should be eliminated.

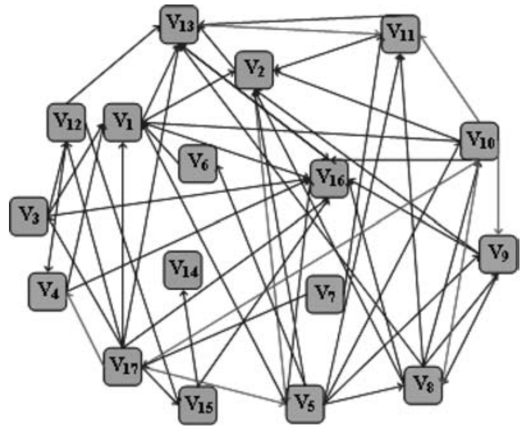

Figure 1. Cognitive mapping of ISPS Code implementation.

Table 3. Centrality values for concepts.

Concepts	Centrality value
V_{16}	11
V_5, V_{10}, V_{13}, V_{17}	10
V_8, V_1	9
V_2	8
V_{11}	7
V_7, V_9	6
V_{12}	5
V_3, V_4, V_{15}	4
V_6	2
V_{14}	1

To quantitatively support this stage, centrality value for each concept can be guided. Centrality of a concept is a measure in application of cognitive mapping approach. Centrality means a reference point to indicate the importance of a concept in a map (Eden et al., 1992). To compute the centrality, the row/column sums of the absolute values (means the direction of the links is ignored) of existing relations are principally considered. Table 3 gives the computed centrality values for each concept of the problem at hand.

According to the initial findings, time constraints at port period are appeared as the most significant matter in ISPS practice at ports. Hence, the relevant maritime authorities need to reduce time-consuming requirements of ISPS Code. To do so, the centrality values and the proposed network in Figure 1 can collaboratively be utilized. Just to name a few underlined issues in detail, the current procedures for security plan and essential visitors' control can be revised. Relevance to ensure collaboration between maritime shareholders, the compliances between MARSEC levels for ships and port authorities need to be rearranged. In addition, the influences of expectations from shipboard personnel, which increase the crew fatigue and stress, should clearly be eliminated. In respect to the centrality values of concepts, a number of enhancement strategies with priorities towards ISPS Code practice at ports can be suggested to maritime authorities.

4 CONCLUSION

Ensuring regulatory compliances with participations of different shareholders in maritime industry is one the focal issue. An effective maritime legislation extremely depends upon the consensus among the market players and relevant international authorities. Specifically, this paper mainly deals with exploring the potential influences of the ISPS code practice at marine ports. Hereto, a number of industrial feedbacks on ISPS practice at ports, which pictures a socio-technical phenomenon, are gathered. To solve this kind of dilemmas, analytical techniques are generally inadequate for dealing with interrelationships or causalities among a set of individual and social concepts. Instead, this paper used cognitive maps to cope with this type of causalities. It underlined some hints to support probable revision efforts on ISPS Code from an interdisciplinary viewpoint. The proposed decision analysis based on a cognitive mapping approach ensured an invaluable findings and straightforward roadmap for the further studies on enhancement of maritime security.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

17.6 Dynamic component of ship's heeling moment due to sloshing vs. IMO IS-code recommendations

P. Krata
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The comparative study of the dynamic component of heeling moment due to sloshing in ships' partly filled tanks is presented in the paper. The characteristics of heeling moment are obtained in the course of experimental tests and numerical simulations. The heeling moment is decomposed and the research is focused on the dynamic component resulting from liquid movement. The results of the research are compared to the computations performed in accordance with the IMO IS-Code recommendations. The need for amending of the intact ship stability assessment procedure is suggested.

1 INTRODUCTION

1.1 *Sloshing phenomenon as one of factors influencing safety of a vessel at seaway*

The dynamic behavior of a vessel at the sea is greatly affected by the dynamics of moving masses existing onboard. The cargo securing procedures ensure avoiding moving of a loose cargo, but the liquids contained in partly filled tanks cannot be avoided at all. Regardless the strength calculation the effects of sloshing should be also taken into consideration in the course of vessel's seakeeping prediction and her transverse stability assessment.

Liquid sloshing phenomenon is a result of partly filled tank motions. As a tank moves, it supplies the energy to induce and sustain the fluid motion (Akyildiz & Unal 2005). Both the liquid motion and its effects are called sloshing. The interaction between the ship's and tank's structure and the water sloshing inside the tank consists in the constant transmission of energy. As the ship rolls, the walls of a partly filled tank induce the movement of water.

In such an attitude ship's seakeeping behavior which comprises the notion of her stability is one of the researched key issues leading to the increase in understanding of the safety qualifying factors.

1.2 *Intact ship stability assessment*

The accuracy of ship's transverse stability assessment is the important factor in the vessel's exploitation process. The ship's loading condition of insufficient stability may induce a list, a strong heel and even a capsizing. Contrary to such state, the excessive stability causes high values of mass forces acting on cargoes and machineries due to a strong accelerations. Therefore, any scientific efforts towards the better ship's stability evaluation are worthy to be undertaken. The influence of sloshing phenomenon on the ship's stability is one of the issues to be considered.

The vessel's stability calculation and evaluation, made on-board nowadays, is based on the stability criteria published by the ship's classification societies. These criteria are mainly based on the A749(18) Resolution of International Maritime Organization. The resolution and their later amendments are known as the Intact Stability Code.

The criteria qualify the shape of the righting arm curve. In addition, the weather criterion is to ensure the sufficient stability of the ship to withstand the severe wind guests during rolling. Although the weather criterion is a very simple model of dynamic ship's behavior, the static stability curve is used. Anyway, the weather criterion is the only, which is partly based on the model of heeling phenomenon not only on the statistic data, while the rest of criteria are based on the statistics of historical disasters only (Francescutto 2002).

According to the IMO recommendations the righting lever curve should be corrected for the effect of free surfaces of liquids in tanks. The correction may be done by any of three accepted methods (IMO 2002):

- correction based on the actual moment of fluid transfer calculated for each angle of heel;
- correction based on the moment of inertia of tank's horizontal projection (simple pendulum model);
- correction obtained form the simplified formula given in the Intact Stability Code.

All of the three mentioned above methods of free surface correction calculation consider the static attitude towards the sloshing phenomenon only. They also do not consider the localization of the tank within the hull of the ship and the localization of the rolling axis. The only advantage of current compulsory corrections is the simplicity of their calculation.

2 RESEARCH INTO THE PRESSURE DISTRIBUTION IN A MOVING TANK

2.1 *Research assumptions*

The scheme of undertaken research comprises physical model tests and numerical simulations as well. The admitted assumptions refer to both and they describe dimensions of the model tank, its movement geometry and characteristics, tank's filling level.

The oscillating movement, which induces the sloshing phenomenon, is described fair enough by the harmonic function. The research into the pressure distribution due to the sloshing was performed for a variety of the external excitation parameters. The period of the oscillation varied from $T = 2{,}6\,\text{s}$ to $T = 6{,}5\,\text{s}$. The lever *os*, as the distance between the center of the tank and the rotary motion axis, was changed from $os = -0{,}718\,\text{m}$ to $os = 0{,}718\,\text{m}$. The positive value of *os* describes the tank's localization beneath the rolling axis and the negative value of *os* describes the tank's localization above it. The amplitude of tank's rotary motion during the model tests and numerical simulations, assumed to be 40°. It reflects the heavy seas conditions and enables to make the conclusions for worst possible condition at the sea. The tank filling level assumed to be 30%, 60% and 90%.

2.2 *Experimental investigation*

The experimental research into the sloshing phenomenon was performed in Ship Operation Department of Gdynia Maritime University. It enabled to measure the dynamic pressure distribution on the sidewall of the model tank and in its upper corner (Krata 2006). The experimental investigation on the pressure distribution due to sloshing required the arousing of the sloshing phenomenon. After that, the dynamic pressure time history in selected spots were measured and recorded. To achieve this, the test apparatus was designed and built (Krata 2006).

The main part of the apparatus is the tank. It is equipped with pressure transducers and an inclinometer. The tank is forced to oscillating movement that excites the water movement inside it. The dimensions of the model tank are: breath – 1,040 m, length – 0,380 m, depth – 0,505 m.

The assumption of plane tank's oscillation and the neglected water viscosity, results the two-dimensional character of water flow inside the tank (Warmowska, Jankowski 2005). It allowed equipping the tank with one set of pressure transducers, fixed in the middle line of the tank. The pressure transducers were installed evenly alongside the vertical wall of the tank and in the roof of the tank close to the upper corner. The experimental setup is shown in Figure 1. The schematic plan of the apparatus is shown in Figure 2.

The location of pressure transducers installed in the front wall of the tank and in its upper corner is specified in the Table 1. Any further details are described in (Krata 2006).

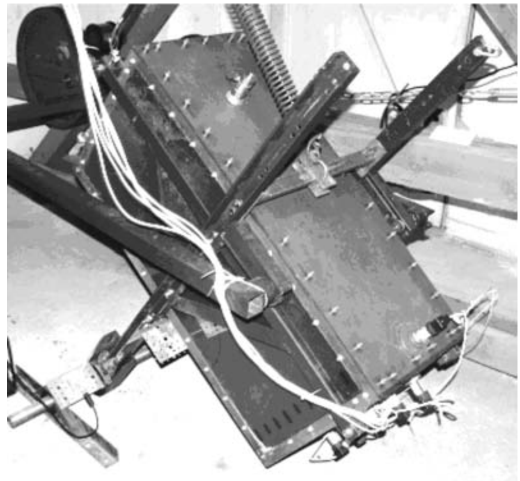

Figure 1. The experimental setup (the tank placed above the shaft – one of possible cases).

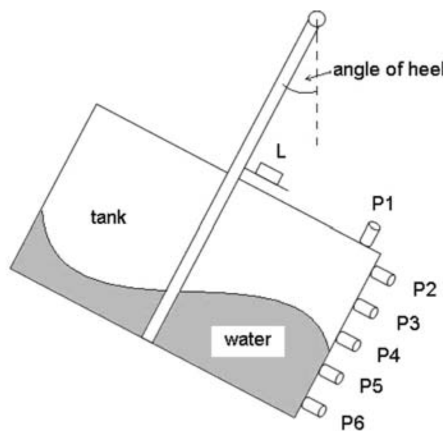

Figure 2. The scheme of the testing apparatus and the localization of dynamic pressure gauges named P1 to P6 and the inclinometer L.

Table 1. Geometry of pressure gauges installation.

No. of pressure gauge	Elevation above tank's bottom [mm]	Horizontal distance from the tank's wall [mm]	Vertical distance between gauges [mm]
P1	505	60	
P2	435	0	70
P3	340	0	95
P4	245	0	95
P5	150	0	95
P6	55	0	95

The analog signals received from the sensors were sampled and transformed into discrete digital signals by the 12-bit A/D card and then they were recorded. The maximum working frequency of the measuring device was 1000 Hz. Thus, the aliasing distortions of the measured signal were avoided, because the measuring instruments were much faster than the required Nyquist rate for the sloshing phenomenon.

The further digital signal processing was carried out. The main operation was low pass filtering for high frequency noise reduction. The filtering enabled to decompose the recorded digital signal and emerged the non-impulsive dynamic pressure component.

2.3 *Numerical simulation*

The pressure distributions obtained in the course of the experimental investigation were completed by the results of numerical simulations. The simulations of sloshing phenomenon were performed by the computer program "Tank" by M. Warmowska, used for the estimation of the dynamic pressure distribution. The sloshing problem was described by two-dimensional model. It was also assumed that the liquid is non-viscid, incompressible, of constant density. As the flow of the liquid assumed to be irrotational, the potential theory was used to solve the sloshing problem (Jankowski, Warmowska 1997).

The numerical simulation of sloshing phenomenon was performed for the oscillation and tank's geometry corresponding with the suitable geometric parameters of the experimental investigation. The program allows computing time history of dynamic pressures in ninety points around the tank's model. The control points are situated along vertical walls, the bottom and the tank's roof. The correctness of the simulation results was verified experimentally (Krata 2006).

3 HEELING MOMENT DUE TO SLOSHING

3.1 *Computation of heeling moment*

The pressure distribution on the walls of the tank was obtained in the course of the experimental tests and numerical simulation. The results of the research enable to compute a heeling moment due to the liquid's sloshing. The heeling moment $\boldsymbol{M}$ was calculated according to the following formula:

$$\boldsymbol{M} = \int_S \boldsymbol{r} \times \boldsymbol{n} \cdot p \, ds \tag{1}$$

where: S – the surface of the tank's walls; $\boldsymbol{r}$ – the position vector of the considered point on the tank's wall; $\boldsymbol{n}$ – the normal vector; p – the local pressure on the tank's wall.

Due to the two-dimensional character of the considered flow in the tank, the heeling moment is a vector of a direction perpendicular to the plane of the tank's movement. As the transverse stability of a ship is assumed to be considered, the heeling moment has one spatial component only, as follows:

$$\boldsymbol{M} = \left[M_x, M_y, M_z\right] = \left[M_x, \quad 0, \quad 0\right] \tag{2}$$

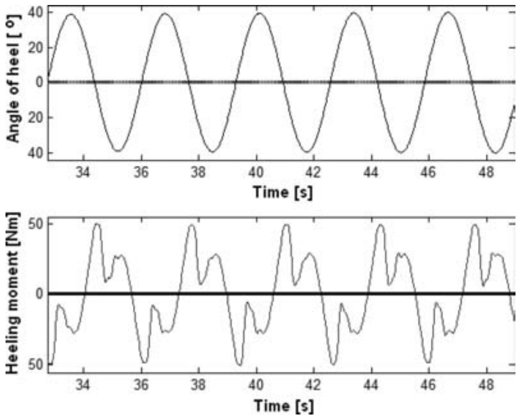

Figure 3. The time-domain presentation of the computed heeling moment due to sloshing.

where: M_x, M_y, M_z – spatial components of $\boldsymbol{M}$ vector, determined about the x, y and z axis in the reference system fixed to the vessel.

As the direction of the heeling moment is fixed and steady in the time domain, the heeling moment due to sloshing may be described by the value of M_x spatial component. The resultant moment obtained from the formula (1) represents one time-step only. The computation of heeling moment should be performed for at least one period of roll. Thus, the pressures have to be investigated for at least one period of ship's roll as well, but actually they were obtained for the longer time comprising few rolling periods. The example of the heeling moment history graph is presented in Figure 3.

The time domain presentation of the computation results can be useful when the ship's rolling is to be computed on the basis of movement equations. In such case, the heeling moment due to sloshing is one of the components of total heeling moment rocking a vessel at seaway.

3.2 *Linearization*

The time-domain manner of presentation of the heeling moment due to sloshing which is shown in Figure 3 as a moment history graph is not convenient in respect of traditional ship's stability assessment (Krata 2008). Such stability assessment is not based on the movement equations, but on the static stability curve (IMO 2002). The curve presents the righting arm GZ in the angle of heel domain and the righting arm is reduced by the statically calculated free surface correction. Therefore, the most convenient way to present the results of the heeling moment calculation due to the sloshing of liquid in a partly filled tank is the angle of heel domain graph.

The interpretation of the results of heeling moment computation is much more convenient in angle of heel domain. The main disadvantage of such presentation is the hysteresis, which is the effect of wave type phenomena taking place inside the moving tank.

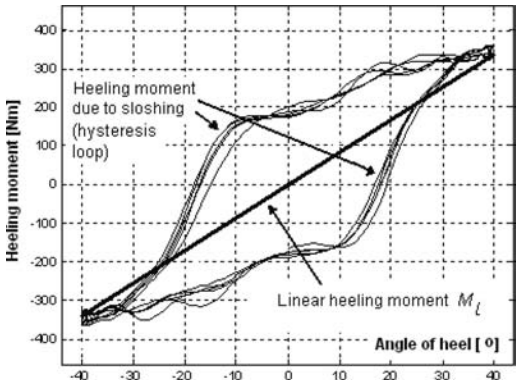

Figure 4. The example of the linear heeling moment, for the filling level 30% and $os = -0{,}718$ m.

The disadvantage can be removed by the linearization process (Krata 2008).

As the main task of the research is more reliable stability assessment with regard to the sloshing phenomenon, the linearization should refer to the ship's stability criteria, especially the weather criterion. The area under the *GZ* curve is qualified within the weather criterion, which represents the work of heeling moment due to wind guests when a ship rolls, so the linearization of the researched heeling moment should be based on the work of the moment as well. The linearization method applied to the heeling moment due to the sloshing of liquids is based on the formula:

$$\int_0^{\varphi_{40}} M_{(\varphi)} \cdot d\varphi + \int_{\varphi_{40}}^{0} M_{(\varphi)} \cdot d\varphi = 2\int_0^{\varphi_{40}} M_l \cdot d\varphi \tag{3}$$

where: M – heeling moment due to sloshing; M_l – resultant linear heeling moment due to sloshing; φ – angle of ship's heel; φ_{40} –angle of heel equal 40° (given in radians).

The formula (3) ensures equality of works done by the researched heeling moment and linear heeling moment due to sloshing. Thus, the method may be called the equivalent work method. The example of linear heeling moment due to sloshing is presented in Figure 4.

The linear function of heeling moment can be determined by the fixing of two in-line points having the coordinates (φ, M). One of them is the point (0, 0) and the second one the point (40°, M_{l40}). Therefore, the complete description of the linear heeling moment obtained in the course of the research may be done by one scalar only, which is convenient for any further analysis.

3.3 *Extraction of dynamical component of the heeling moment due to liquid sloshing*

The moment M heeling a ship in consequence of liquid existence carried in any partly filled tank, may be decomposed into two components. One of them is the moment M_m of liquid weight and the second is the heeling moment M_{RB} due to the movement of fluid inside the tank. The heeling moment due to liquid sloshing in vessel's tanks can be described in every time-step by the formula:

$$M = M_m + M_{RB} \tag{4}$$

where: M_m – heeling moment due to the weight of "frozen" liquid in tank; M_{RB} – heeling moment due to the movement of fluid inside partly filled tanks.

The simple sum of moment components analogous to the formula (4) was applied to the linear heeling moment M_l calculated according to the formula (3) for all considered cases. Thus, the component M_{RB} of the heeling moment due to sloshing abstracts the static effect of liquid weight in ship's tanks. Such abstraction capacitates to bear comparison of the performed research results with the quasi-static heeling moment computed according IMO IS-Code recommendations.

4 RESULTS OF THE RESEARCH

4.1 *Comparison of the research results and IMO IS-Code recommended computation*

The research is focused on the comparative analysis of the heeling moment components arising from the liquid movement inside ship's partly filled tanks. One of them is obtained in the course of the research and it reflects the dynamic attitude towards the sloshing phenomenon. The other is calculated according the IMO IS-Code recommendations and it is of quasi-static type. The computation formulas resulted from IS-Code prescriptions.

The heeling moment M_{IMO} due to liquid's existence inside any partly filled tank may be decomposed into two components according to the formula:

$$M_{IMO} = M_m + M_{RIMO} \tag{5}$$

where: M_m – heeling moment due to the weight of "frozen" liquid in tank; M_{IMO} – heeling moment of the transfer of the liquid's center of gravity.

The moment M_m is taken into consideration in course of the calculation of the ship's center of gravity and it assumes the liquid to be "frozen" at the angle of heel equal 0°. It is important to notice, that the M_m component is equal in formulas (4) and (5). Therefore, the remaining components M_{RB} and M_{IMO} of the heeling moment may be compared. The component M_{IMO} of the heeling moment can be calculated at any of the three accepted method. The simple pendulum model is considered as safest for the ship therefore the free surface correction based on the moment of inertia of tank's horizontal projection was applied in the course of the further comparison.

The quasi-static component M_{IMO} of heeling moment is a function of sine of the angle of heel. Anyway, it could be compared to the researched linear component of the heeling moment due to sloshing

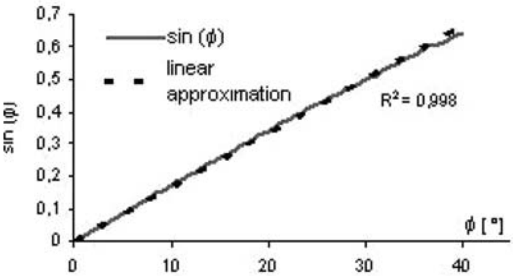

Figure 5. Linear approximation of sine function.

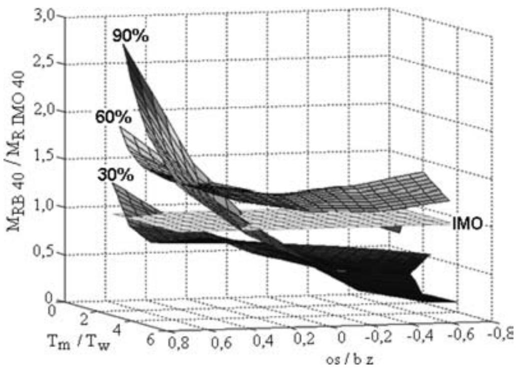

Figure 6. Non-dimensional component of heeling moment due to liquid movement in partly filled tanks.

for the range of angles of heel where the sine function may be approximate by linear function fair enough. The reasonable range of such linear approximation is about 40°, which shows Figure 5.

As the sine function is almost linear up to the angel of heel 40°, the components M_{RB} and M_{IMO} of the heeling moment may be compared. They both have the zero values for the zero angle of heel, so their comparison may be done as the comparison of their values for the angle of heel equal 40°. Thus, the values M_{RB40} and M_{IMO40} are analyzed instead of the moment graphs. The comparison of the M_{RB40} values obtained in the course of the research and the M_{IMO40} computed according to the IMO recommendations is shown in Figure 6.

The graphs showing analyzed values of the component of heeling moments are prepared as non-dimensional referred to the value M_{IMO40} of static free surface correction. The excitation period T is referred to the first harmonic natural sloshing period of a liquid in model tank T_w. The scope of T/T_w ratios reflects the wide variety of characteristics they can take place on board of ships at different loading conditions. The distance *os* between the center of the moving tank and the rotary motion axis is referred to the breath of the tank b_z. The three graphs marked 30%, 60% and 90% are plotted for the corresponding three levels of tank filling. The reference surface marked IMO is plotted for M_{IMO40} values calculated according the IMO IS-Code requirements.

4.2 *Analysis of the obtained results*

The quasi-static heeling moment component represented by the free surface correction described in IMO IS-Code depends on the shape of a partly filled tank only. Presented results of the research prove the significant influence of other factors. One of the most important is the localization of the tank referred to the vessel's rolling axis os/b_z. The excitation period referred to the first harmonic natural sloshing period of a liquid in model tank seems to be less important. The lowest investigated values of T/T_w ratios can occur for very short ship's rolling period typical for extremely stable ships. In any other cases, the T/T_w ratio does not play the important role.

The graph presented in Figure 6 enables the identification of potential danger to a vessel caused by the movement of liquid in partly filled tanks. Any value of analyzed heeling moment component higher than the reference level IMO should be considered as potentially perilous to a vessel because her transverse stability can be worse than calculated according to IS-Code recommendations.

The surface plotted for 30% of tank filling demonstrates that such a low level of filling does not need to be considered as risky one. The influence of liquid sloshing is weaker than that taken into account in the course of standard stability assessment. The only trespass of the reference IMO level is noticed for the shortest rolling period, which can take place in the case of large GM only.

The surface plotted for 60% tank filling level reveals the fair conformability of the research results and IS-Code recommendations for partly filled tanks situated above the ship's rolling axis and the considerable transgression for tanks placed below the rolling axis. The potentially dangerous underestimation of the liquid sloshing influence on the ship's transverse stability occurs for all researched rolling periods.

The surface plotted for 90% of tank filling prove the potentially perilous situation, which can take place for high levels of tank filling. The effect of liquid sloshing is slightly overrated for partly filled tanks situated above the ship's rolling axis when computed according to IS-Code. Such an effect may be considerably underestimated for tanks sited below the rolling axis, for instance double bottom tanks.

5 CONCLUSIONS

The movement of liquids in partly filled ship's tanks affects her stability and therefore it is considered in course of the stability assessment procedure according to the IMO recommendations. The results of the research presented in the paper points that the very simplified methods recommended by IMO could be improved and reach better accuracy to meet the modern requirements of ship's exploitation.

The presented comparative analysis of the components of heeling moment reveals some weaknesses of IS-Code. The use of current IS-Code recommendations may lead to considerable underestimation of free surface effect. This results from the quasi-static attitude towards the sloshing phenomenon. The analysis proves that the dynamic movement of liquids in partly filled tanks should not be neglected. The results of the research can contribute to the further investigation of the new formula of free surface correction comprising the dynamics of sloshing phenomenon.

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17.7 The influence of the flooding damaged compartment on the metacentric height ship type 888

W. Mironiuk
Polish Naval Academy, Gdynia, Poland

ABSTRACT: Research on damage stability and unsinkability is a valuable source of knowledge of behaving a ship while flooding its compartments. In the paper, a short description of accidents and damages of Polish warships taking place in 1985–2004 is presented. The time when compartments are flooded (t_f) and stability parameters are one of the key elements which have influence on a rescue action. The knowledge of the time mentioned and a metacentric height (GM) are very important for a commanding officer making decisions while fighting for unsinkability and survival of the ship. To provide the information about the time t_f a new method was designed. The method was tested experimentally and results of the tests are presented in the paper. In the experiments, the flooding process of compartments in a ship of the type 888 was simulated. The results of the experiments can be a base to define general rules to make proper decisions during the process of damage control.

1 INTRODUCTION

Even highly organized fleets struggle with accidents and technical breakdowns which cannot be completely eliminated. The breakdowns can be classified based on their causes. The basic causes of the breakdowns are: warfare, defects of materials and defects within the production process, constructional defects, technological defects in the process of renovation, material's wear and tear, not meeting the requirements in operating and servicing an equipment, not taking security measures while storing dangerous cargoes, e.g. explosive materials, petroleum products and other chemical components of serious fire hazard.

A partial or total loss in functionality of mechanisms and installations can occur both during warfare and during daily operating a ship.

Failures caused by navigational mistakes or wrong maneuverability represent a group of ship accidents and breakdowns which can lead to dangerous lost of floating of a ship due to flooding its compartments.

The statistical data prepared by the Polish Navy Commission of Warship Accidents and Breakdowns reveal 156 warship accidents and breakdowns between 1985 and 2004 year. The data mentioned are presented in Figure 1. (Korczewski & Wróbel, 2005).

In a situation of a breakdown crew activities deciding about ability of a warship to fight should be directed to take a proper actions during the process of damage control and to protect stability, sinkability and maneuverability of the ship.

Exercises within the confines of the process of damage control, apart from construction solutions, increase the safety of both a ship and crew. Training is carried out in well prepared training centres. The centers are equipped with ship models designed

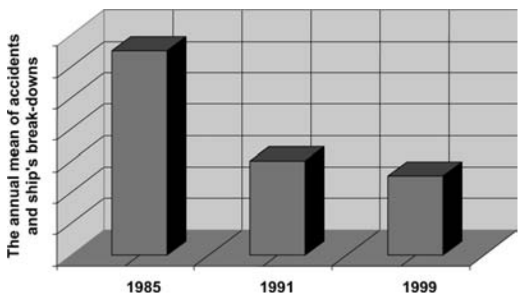

Figure 1. The overall structure of accidents and breakdowns between 1985–2004.

for simulating failure states which most frequently occur while operating a ship. The same models were also used in the experiments reported in the paper. One of the goals of the experiments mentioned was to determine the following parameters: t_f and GM.

The information about t_f and stability parameters is very important for a commanding officer. It enables him to make a proper decision during the process of damage control. The officer, based on the information should determine the point in time, when further fighting for unsinkability is senseless and when all effort should be directed to save the crew and documents (Miller, 1994).

2 CALCULATING THE TIME OF FLOODING SHIP'S COMPARTMENT

When calculating t_f, first, the velocity of water running through the damaged hull has to be determined. The water flowing through a hole can be compared to liquid flowing from a tank of a surface A. The water velocity can be obtained from the following formula (Troskolanski 1961):

$$v_w = \sqrt{\frac{2 \cdot g \cdot h_z}{1 - \left(\frac{A_0}{A}\right)^2}} \tag{1}$$

where $A_0 =$ cross section of a hole; A = horizontal cross section of a tank; g = acceleration due to gravity, and $h_z =$ height of a liquid inside the tank.

Because the surface of a hole is much smaller than a sea surface, the water velocity can be obtained according to Torricelli's formula (Troskolanski 1961):

$$v_w = \sqrt{2 \cdot g \cdot h} \tag{2}$$

where $h =$ depth of a hole.

For the real liquid the formula (2) can be presented as follows (Troskolanski 1961):

$$v_w = \varphi \cdot \sqrt{2 \cdot g \cdot h} \tag{3}$$

where $\varphi = 0,97 \div 0,98$ – the velocity coefficient dependant on the kind of liquid.

The equation (3) is applied when the water surface inside a hull is below a lower edge of a hole, i.e. for a constant pressure of the water. When the water pressure is changeable (the water surface inside a hull is above an edge of a hole and still grows up) the velocity of the water flowing to the compartment can be obtained according to the formula (Troskolanski 1961):

$$v_w = \varphi \cdot \sqrt{2 \cdot g \cdot (h - h_0)} \tag{4}$$

where $h_0 =$ height of liquid inside a tank above an edge of a hole.

The hole in the body can have a different shape and dimension dependant on the reason of damage. The shape of the hole influences a quantity Q of the water flowing to the compartment. The quantity Q depends on ν, which in turn is a product of coefficient φ and narrowing coefficient $\chi = 0,61 \div 0,64$ (Troskolanski 1961). Therefore, the quantity of water Q flooded to the interior compartment can be obtained from the formula (Troskolanski 1961):

$$Q = A_0 \cdot \nu \cdot \sqrt{2 \cdot g \cdot h} \tag{5}$$

When the pressure of the water is changeable the quantity of water Q inside the compartment is calculated from the formula (Troskolanski 1961):

$$Q = A_0 \cdot \nu \cdot \sqrt{2 \cdot g \cdot (h - h_0)} \tag{6}$$

The time t_f is as follows (Troskolanski 1961):

$$t_f = \frac{V}{Q} \tag{7}$$

where V = the volume of the water inside a compartment.

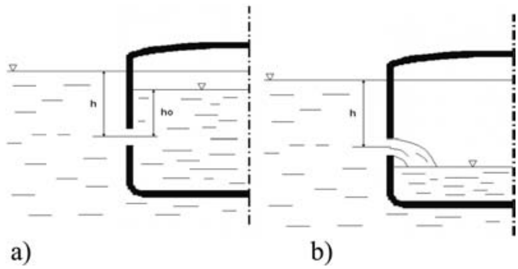

Figure 2. Compartment being flooded: a) with constant water pressure, b) with variable water pressure.

3 CALCULATING THE VOLUME OF DAMAGED COMPARTMENTS

The calculation of t_f was conducted for a damaged engine room and auxiliary power plant of the ship type 888. To enable the calculations above simulating computer program was built. The program made it possible to fix basic and necessary parameters to make a correct evaluation of the state of a ship. In turn, the information about the parameters mentioned above makes it possible to take proper decisions during the process of the damage control.

3.1 *Computing the volume of damaged compartments*

The volume of a damaged compartment is necessary to calculate the time t_f. The lines plan of the ship's hull is used to compute the theoretical volume v_t. Moreover, the plan was also used to make extracted sections on ribs number 25, 30, 35, 40, 45, 50 of the damaged compartment. The sections are shown in Figure 3 (Tarnowski 2008, Kowalke 2006).

The area of the sections was calculated to estimate the accurate volume of the damaged compartment. Integral curves of sectional areas, obtained in this way, are presented in graphic form as a multinomial degree 7 in Figure 4.

Using section areas and a distance between them, the theoretical compartment volume v_t can be calculated, by the formula (Deret 2003, Dudziak 2006):

$$v_t = \sum \frac{(F_i + F_{i+1}) \cdot l_w}{2} \tag{8}$$

where $l_w =$ the distance between sectional areas, and $F_i, F_{i+1} =$ section areas.

3.2 *The permeabilities calculation*

The volume of the empty compartment was calculated by means of the computer program. The real quantity of the water, flooding the compartment, is less than the theoretical volume of the compartment

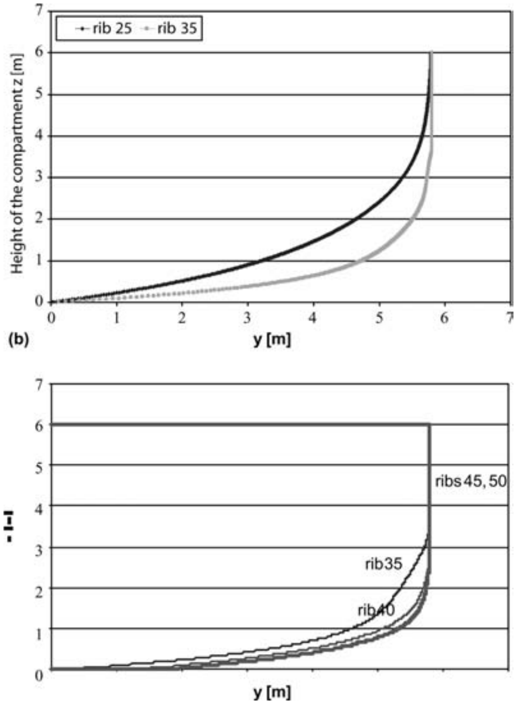

Figure 3. Sections of compartments: a) auxiliary power plant, b) engine room.

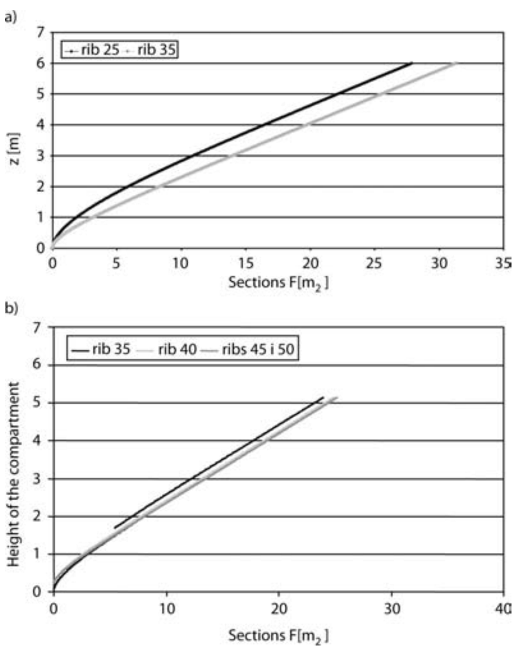

Figure 4. Integral curve sectional areas: a) auxiliary power plan; b) engine room.

due to the volume of all mechanisms and devices inside the compartment. Usually, to calculate a real quantity of the water, the permeability of flooding compartment μ is used. The values of permeabilities

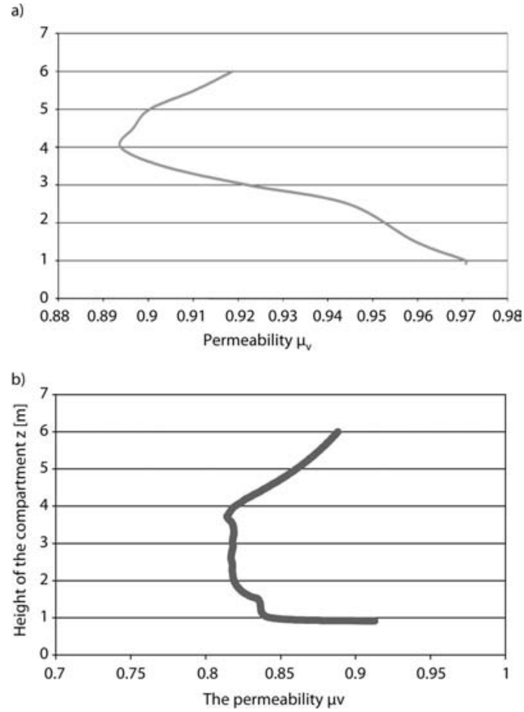

Figure 5. Graph of the permeability μ_v : a) auxiliary power plant, b) engine room.

for two compartments are calculated by the formula (Deret 2003):

$$\mu = \frac{v}{v_t} \tag{9}$$

where v_t = theoretical compartment volume; v – real quantity of the water inside the compartment.

The numerical value of the permeabilities depends on both, a kind and destination of damaged compartment. The permeability of the compartment μ, which is announced in the SOLAS Convention, is usually used to calculate the real volume of the compartment. In preliminary research, permeabilities of both, the auxiliary power plant and the engine room were estimated. Their value depends on the height of the water inside the compartment. The graph of the permeabilities is shown in Figure 5 (Tarnowski 2008, Kowalke 2006).

The average value of the permeability for chosen compartments, obtained as a result of experiments, is comparable with the value of the SOLAS Convention and equals 0,85.

3.3 *The model of simulation for damaged compartment*

The simulation model of the auxiliary power plant and the engine room, equipped with all main mechanisms and devices, was made in the next part of the research. The view of the compartments being flooded is shown in Figure 6 (Tarnowski 2008, Kowalke 2006).

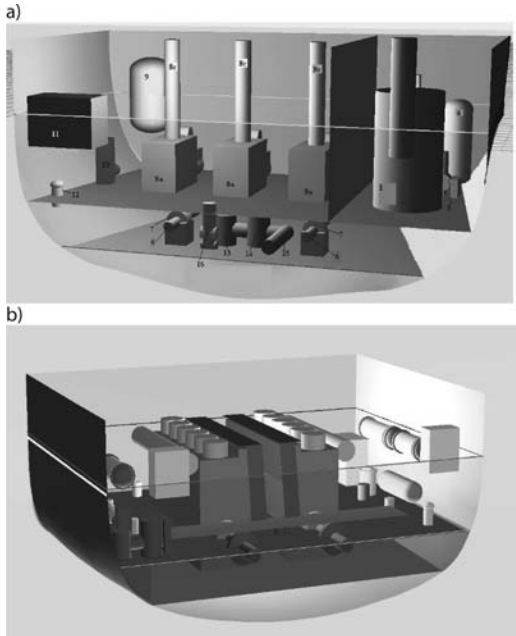

Figure 6. Compartments being flooded: a) auxiliary power plant, b) engine room.

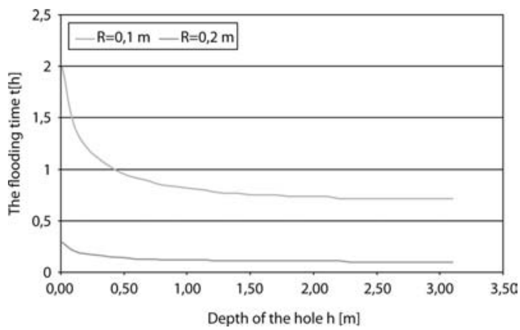

Figure 7. t_f for auxiliary power plant.

4 THE ANALYSIS OF THE INFLUENCE OF DAMAGE PARAMETERS ON THE TIME t_f FOR THE COMPARTMENTS SHIP TYPE 888

The experimental research on t_f for the auxiliary power plant and the engine room ship type 888 was carried out for different parameters of damages. In the research, the place and the dimension of damage were taken into consideration.

In the first stage of the research, t_f for the auxiliary power plant was fixed. The calculations of t_f were made for the following example conditions: ship's draught $T = 4$ m, the dimension of damages $R = 0{,}1$ m and $R = 0{,}2$ m (R denotes radius). The holes were placed from 0,1 m to 3,0 m below the surface of the sea. The results of the research are shown in Figure 6.

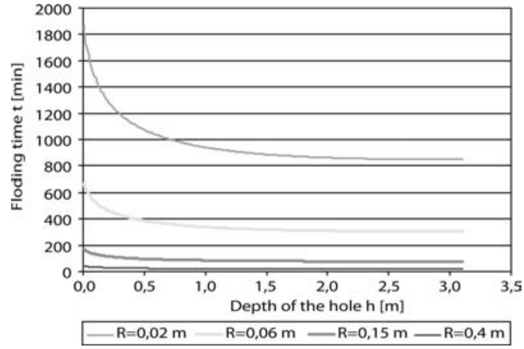

Figure 8. t_f for engine room.

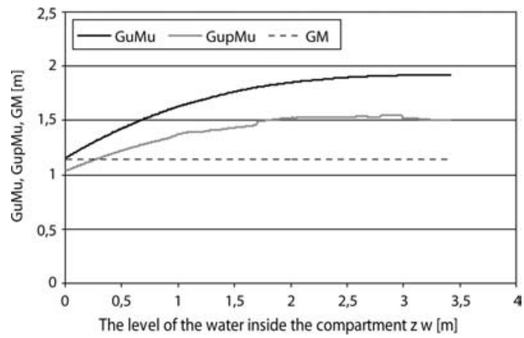

Figure 9. Metacentric height
GM- initial metacentric height (before demage);
GuMu- metacentric height while flooding engine room;
GupMu- metacentric height while flooding engine room with free surface.

In the next step, t_f for the engine room was calculated. The results of the research are shown in Figure 8.

Figure 8 presents that t_f for the compartment with dimension of damage $R = 0{,}4$ m, placed 3 m below the surface of the sea, equals 3,4 minutes. This time is too short to seal the damage. Consequently, further activities of crew should be directed to protect spreading the water covering interior of the ship and to strengthen the construction of the watertight bulkhead.

5 THE METACENTRIC HEIGHT CALCULATION

The next part of the research was devoted to estimate a metacentric height while flooding a damaged compartment. To calculate this parameter the added mass method was used. The result of calculations is shown in Figure 9.

To calculate the metacentric height the free surface effect was taken into consideration. Figure 10 implies that in the early stage of flooding the compartment, the metacentric height GupMu, is less than GM. In the later stages, GupMu increases and improves stability of a ship. This situation takes place due to adding a mass in the lower part of the ship.

6 CONCLUSIONS

The method of determining the permeability presented in the paper enables us to make calculating the time t_f more accurate.

The time t_f depends on both the dimension and the place of a damage.

The knowledge of the time t_f and metacentric height allows a commanding officer to make decisions while fighting for unsinkability and for the survival of the ship.

The modified method can be used to calculate the time t_f for ship type 888 with different types of hull damages. The method can be adopted for different type of warships.

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Marine Navigation and Safety of Sea Transportation – Weintrit (ed.)

17.8 Intelligent evaluation system of ship management

Q. Xu & X. Meng
Information Science and Technology College, Dalian Maritime University, Dalian, China

N. Wang
Marine Engineering College, Dalian Maritime University, Dalian, China

ABSTRACT: The security of maritime traffic is a significant part of intelligent maritime traffic. It can reduce to ship maneuvering and collision avoidance by macroscopic. Eighty percents of marine accident induce by human factor from research data. So some researches about intelligent computer evaluation system to reduce the accident of human caused have emerged. Intelligent evaluation system of ship maneuvering can calculate the status of ship and getting the data of ship around, and then adopt fuzzy comprehensive evaluation method to calculate the collision risk and evaluate the operation of navigator. If it has danger of collision risk or the navigator adopts irrational operation scheme by calculating, the system will send message to the navigator. The navigator must affirm the messages, if there is not affirmance, the system will adopt collision avoidance measures or other rational operations automatically at the critical moment.

1 INSTRUCTION

The environment of navigation has great change in recent years. This make the maneuvering of ship be more difficult. At the same time, ARPA (Automatic Radar Plotting Aids), GMDSS (Global Maritime Distress & Safety System), GPS (Global Positioning System) and ECDIS (Electronic Chart Display and information System) etc. have applied in navigation, the number of crew is decreasing. This make more serious for manipulator. Eight percents of shipwreck accident were caused by human factor according to investigation. (Guedes Soares & Teixeira 2001, Gaarder et al. 1997) To decrease the accident, and increase the safety of navigation, researchers bring in automatic maneuvering to instead of human's job. This method makes up for some human's shortage, and increases work efficiency. However, they find that some accidents related to automatic equipment late years. Some person research the strand accident of "Royal Majesty" find that automation changed the style of working, and formed a new way to making mistake. So this paper proposes an intelligent evaluation system of ship maneuvering, human is the major in system, the system can calculate the status of ship and collision risk, then display it functionality. If the vessel gets into the critical area and time, the system will adopts corresponding strategy when the navigator does not adopt any measures.

2 HUMAN FACTOR

According data of Japanese Ship Safe Seminar in 1998, 84% shipwreck accident caused by human factor. Other country and region also have similar conclusion. The human's factor attaches importance to navigation safety, which has turn into people's consensus. Human have researched into human's factor indefatigably for ages, and form an academic domain "Human Factor" (Gaarder et al. 1997). With the purpose of enhancing security and efficiency, it is an extremely practical integrated subject. Human factor can bring positive impact on traffic at sea, for example human's cognitive and perceive capacity is stronger than instrument and equipment. It can bring negative impact reversely, for example making a mistake easily, forgetting memorial affair, limited analysis precision. Human's fault is one of major reason in shipwreck, and comes in for human's highly respect.

Fault is the property of human, removing the fault completely is an unpractical. Therefore, we should adopt measures to reduce the harmful consequence brought by man. To achieve a job, division of labor is an efficacious practice. BRM (Bridge Resource Management) and BTM (Bridge Team Management) at sea are discussed more by researchers of last year. VTS is a system of construct with vessels taking part in VTS and VTS organization. It has correction capability on the part of whole system. VTS attendant will correct it when ship has breach of regulation phenomenon. Another method to reduce fault is using alerting equipment. The equipment send out warning to cause human's attention when mistake occurs. For example, ARPA can send out sound and light warning when the DCPA and TCPA are smaller than a setting value. Britain, Germany and Japan develop BNWAS used to monitor steering and sailing on duty. This system used to monitor the alert of navigator, if the equipment detects that navigator cannot perform the duty of his, it will send out gradated outspread warning. At first, it will be in cage, if there is no response it will extend to caption and other sailor's room.

3 INTELLIGENT EVALUATION SYSTEM

Traditional collision avoidance is that the sailor adopts empirical collision avoidance according to self-experience. It depends on navigator's individual intuition to make decision, if the risk is large, it will be easy to make mistake. Collision avoidance expert system and decision-making support system spring up rapidly of late years. They have great auxiliary effect to vessel collision avoidance.

Human is the principal part in the evaluation system of ship maneuvering. We make use of computer and develop intelligent evaluation system of ship maneuvering. The system can gather dynamic information of vessel by AIS, ARPA, infrared and photo electricity equipments (Thomas et al. 2008). The information will be sent to the intelligent evaluation system finally, the system will enter into different model according to encounter situation and environment condition. The result of evaluation is the current situation of ship.

3.1 *The structure of intelligent evaluation system*

The evaluation system consist of many models, including target ship identification, speculation and prediction of encounter status, real evaluation of operation, auto-collision avoidance strategy and risk warning model etc. We can see from Fig. 1, the evaluation system and operation of navigator form a closed-loop control system. The system will evaluate the performance of operation, and send out corresponding signals. In this way it can make up the disadvantage of none precision calculation of human, cut down the probability of human fault occurrence, and secondly make use of human's high adaptability sufficiently.

3.2 *Collision risk calculation*

Ship collision risk calculation is one of the most important parts in the system. The quantification of collision risk experience several stages basically(WU Zhao-lin & ZHENG Zhong-yi 2001). The first one is traffic flow theory which use ship collision rate, encounter rate, collision probability to evaluate the collision risk for special water area. The second is ship domain and arena which is based on human praxiology and psychology. (Fuji & Tanaka 1971), (Goodwin 1975) etc. who use this to calculate collision risk. In the third stage, people have considered the dCPA(Distance at Closest Point of Approach) and tCPA(Time at Closest Point of Approach) in calculation, like (Davis et al. 1980). In the fourth stage, combine dCPA and tCPA, adopt weighting method to calculate collision risk at the beginning (Kearon 1979, Imazu & koyama 1984). This method exist obvious disadvantage that dCPA and tCPA are two different variable. Then people adopt fuzzy theory to combine dCPA and tCPA. At present mostly research are based on the artificial intelligent technology as fuzzy theory, expert system, neural network to calculate the collision risk (LI Li-na 2006).

This paper adopt fuzzy compressive evaluation to calculate CR(collision risk). The comprehensive evaluation result can be used as subjective evaluation, and also can be as objective one. Furthermore, system security is a progressively process. We can get perfect result through assessing the subordination of the factors. So we don't use the weighting of dCPA and tCPA to calculate collision risk, they applied fuzzy comprehensive evaluation in it. There are many factors effecting CR. We only consider the major factors here, the distance between target ship and local ship d, the position of target ship θ, *dCPA*, *tCPA*. So the target factors' discourse domain is:

$$u = \{d, \theta, dCPA, tCPA\}$$

The allocation of target factors weight is:

$$A = (w_d, w_\theta, w_{dCPA}, w_{tCPA})$$

$$w_d > 0,\ w_\theta > 0\ ,\ w_{dCPA} > 0\ ,\ w_{tCPA} > 0, \text{ and}$$

$$w_d + w_\theta + w_{dCPA} + w_{tCPA} = 1$$

Expert recommend:

$$w_d = 0.12, w_\theta = 0.12, w_{dCPA} = 0.38, w_{tCPA} = 0.38$$

Target evaluation matrix is:

$$B = \begin{bmatrix} r_d \\ r_\theta \\ r_{dCPA} \\ r_{tCPA} \end{bmatrix} \tag{1}$$

$$0 \le r_d \le 1; 0 \le r_\theta \le 1; 0 \le r_{dCPA} \le 1; 0 \le r_{tCPA} \le 1;$$

r_d, r_θ, r_{dCPA}, r_{tCPA} are target risk membership.

Distance risk membership function is:

$$u(d) = \begin{cases} 1 & d \le d_l \\ [(d_m - d)/(d_m - d_l)]^2 & d_l < d \le d_m \\ 0 & d > d_m \end{cases} \tag{2}$$

d_l distance of the last minute avoidance
d_m distance of adopt avoidance action
$d_l = K_1 \cdot K_2 \cdot K_3 \cdot DLA$
$d_m = K_1 \cdot K_2 \cdot K_3 \cdot R$
K_1 decided by visibility,
K_2 decided by water area status,
K_3 decided by human factor,
DLA distance of the last minute action,

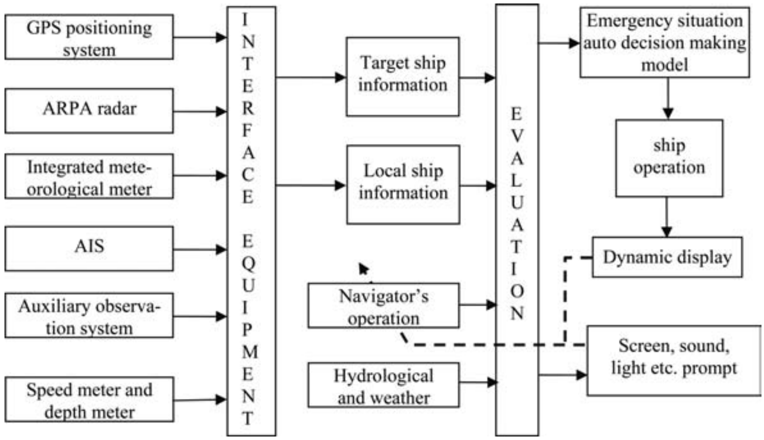

Figure 1. The diagram of evaluation system of ship maneuvering.

R is the radius of arena.

$$R = 1.7\cos(\theta - 19^\circ) + \sqrt{4.4 + 2.89\cos^2(\theta - 19^\circ)}],(0^\circ \le \theta < 360^\circ) \quad (3)$$

Position of target ship membership function:

$$u(\theta) = \begin{cases} \dfrac{1}{1+(\theta/\theta_0)^2}, & 0 \le \theta < 180^\circ \\ \dfrac{1}{(\dfrac{360^\circ - \theta}{\theta_0})^2}, & 180^\circ \le \theta < 360^\circ \end{cases} \quad (4)$$

θ_0 is according to the velocity ratio K of local ship and target ship

$$K = \frac{v_0}{v_t} \quad (5)$$

$$\theta_0 = \begin{cases} 40^\circ & K < 1 \\ 90^\circ & K = 1 \\ 180^\circ & K > 1 \end{cases} \quad (6)$$

dCPA risk membership function:

$$u(dCPA) = \begin{cases} 1 & ,dCPA \le \lambda \\ \dfrac{1}{2} - \dfrac{1}{2}\sin[\dfrac{\pi}{dCPA_0 - \lambda}(dCPA - \dfrac{dCPA_0 + \lambda}{2})], & \lambda < dCPA \le dCPA_0 \\ 0 & ,dCPA > dCPA_0 \end{cases} \quad (7)$$

$dCPA_0 = 1$ n mile,

$\lambda = 2(L_0 + L_t)$, L_0, L_t are the length of local and target ship.

tCPA risk membership function:

$$u(tCPA) = \begin{cases} 1 & tCPA \le t_1 \\ \dfrac{t_2 - tCPA}{t_2 - t_1} & t_1 < tCPA \le t_2 \\ 0 & tCPA > t_2 \end{cases} \quad (8)$$

$$t_1 = \frac{\sqrt{(d_l^2 - \lambda^2)}}{v_s} \quad (9)$$

$$t_2 = \frac{\sqrt{(d_m^{\ 2} - dCPA_0^{\ 2})}}{v_s} \quad (10)$$

According to the fuzzy comprehensive evaluation method.

$$CR = A \cdot B = (w_d, w_\theta, w_{dCPA}, w_{tCPA}) \cdot \begin{vmatrix} r_d \\ r_\theta \\ r_{dCPA} \\ r_{tCPA} \end{vmatrix} \quad (11)$$

Collision risk is:

$$CR = [w_d u_d + w_\theta u_\theta + w_{dCPA} u_{dCPA} + w_{tCPA} u_{tCPA}] \quad (12)$$

4 RESULTS

In a water area, local ship: course 000°, velocity 15 kn, length 75 m, the visibility is better (K1 = 1, K2 = 1, K3 = 1), adopt DLA = 1 n mile. Get the data from ARPA, target ship: position $\theta = 29.5°$, distance d = 3 n mile, relative velocity vs = 26.2 kn, dCPA = 0.4 n mile, tCPA = 7 min, length of target ship 110 m. calculate the collision risk of target ship against local ship.

According to the data and associative formula, we can obtain:
u(dCPA) = 0.8500,
u(tCPA) = 0.3633,
u(θ) = 0.6477,
u(d) = 0.1624.

Divide the collision risk into 5 level:

– I—— 1.00∼0.91
– II—— 0.90∼0.81
– III—— 0.80∼0.71
– IV—— 0.70∼0.61
– V—— 0.60∼0.51

According to this division, 0.56 belong to IV level, middle danger. At this moment, the evaluation system will display this for navigator. Navigator will adopt suitable measures according to the information and self judgment. The evaluation will calculate the encounter status of two ships in real time. The system will send an alarm to navigator for correcting it when navigator adopts irrational operation. If there is not any response at the point of last helm, the system will adopt automatic collision avoidance strategy.

5 CONCLUSION

Navigation is human's job, human factor have finality affect to navigation safety, especially human's fault, and it is one of the major reason of shipwreck. Human's fault is unforeseen and unconquerable completely, so we must adopt additional precautions to improve and make up the affect of human's fault to navigation safety. With the development of information technology, computer is an advantageous auxiliary facility. Human coordinate with computer by constructing intelligent evaluation system of ship maneuvering which makes up human weakness and also solves the problem that computer is not adaptable to environment. It makes use of the advantage of human's adaptability and computer's calculation capacity. Therefore, this is a man-machine associative method, and it is advantageous instrument in navigation.

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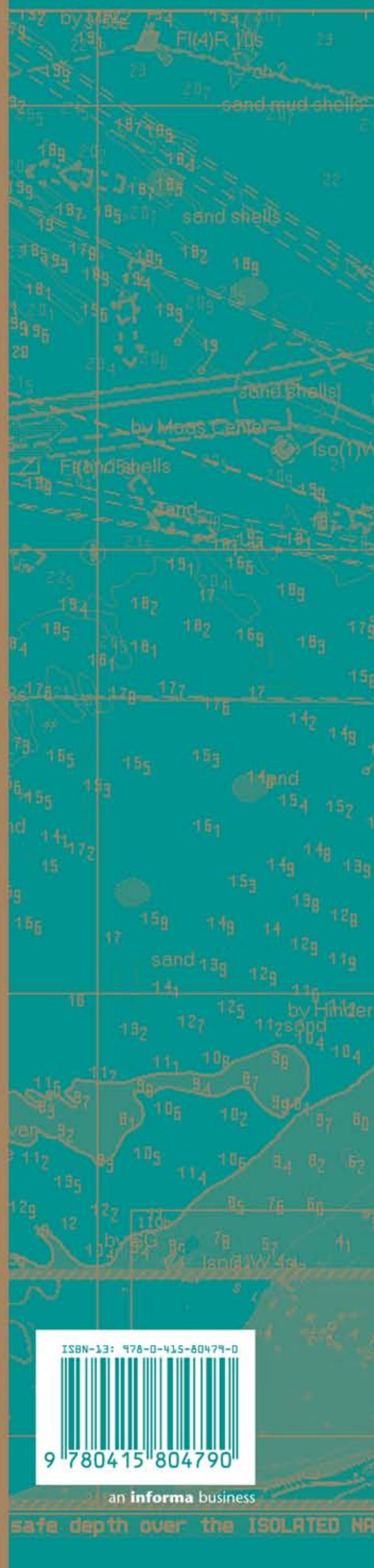

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