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CONTENTS

Editorial preface	5
Marine Technology and Innovation	7
1. BEHRENDT CEZARY, RAJEWSKI PRZEMYSŁAW Analysis of energetic system failures of Polish fishing fleet vessels and their impact on the environment	9
2. KASZYCKI LESZEK Simulator of a nitrogen purging fuel gas line system of the main propulsion boiler on liquefied petroleum gas ships	15
3. KOROSTIL JERZY, KOROSTIL OLGA The use of text models in the formation of heuristics to solve tasks of diagnosing technical objects	22
4. KRYSOSIK-GROMADZIŃSKA AGATA Engine room fire safety	29
5. MONIETA JAN Ship fires caused by primary failure of the fuel filter of the engine driving the generator	36
6. RAZAGHIAN AMIR HOSSEIN, GHASSEMI HASSAN Numerical analysis of the hydrodynamic characteristics of the accelerating and decelerating ducted propeller ...	42
7. TRYCZAK JAKUB ROMAN, ZEŃCZAK WOJCIECH Mathematical models for simulation of layer hydrodynamics of a ship fluidized bed boiler	54
Navigation and Maritime Transport	59
8. DRAMSKI MARIUSZ Extensible event stream format for navigational data	61
9. DRWIĘGA KINGA, GUCMA LUCJAN, GRALAK RAFAŁ A method for reserve determination of the static and dynamic list of liquefied natural gas carriers and its application to the dynamic under keel clearance system in the outer port in Świnoujście	66
10. JANUSZEWSKI JACEK Applications of global navigation satellite systems in maritime navigation	74
11. KASYK LECH Extreme value distributions in the analysis of traffic time on the Świnoujście–Szczecin fairway	80
12. KULBIEJ ERIC Relevance of the relativistic effects in satellite navigation	85
13. LISOWSKI JÓZEF Dynamic optimisation of safe ship trajectory with neural representation of encountered ships	91
14. POSACKA KATARZYNA The influence of economic and geographic conditions on the development of container terminals at the Szczecin and Świnoujście Seaports Authority	98
15. WIŚNIEWSKI BERNARD, SZYMAŃSKI MACIEJ Comparison of ship performance optimization systems and the bon voyage onboard routing system	106
16. WIŚNIEWSKI BERNARD, SZYMAŃSKI MACIEJ Navigation in emission control area zones	116
Transportation Engineering	121
17. CHŁOPIŃSKA EWELINA, KOWBEL RAFAŁ Tangible benefits of using liquefied natural gas fuel in the urban transport of Szczecin	123
18. HANN MIECZYŚLAW, PIOTROWSKI LESZEK, WOŚ KRZYSZTOF A new concept for utilising the Oder waterway in intermodal container transport	129

19. KOZERSKA MONIKA	
Inland waterway transport in Poland – the current state and prospects for development	136
20. LEWANDOWSKI PIOTR	
Attempts to protect the internal market for road transport in specific European Union countries	141
21. ŁOZOWICKA DOROTA, KAUP MAGDALENA, MACHOWSKI ZBIGNIEW	
The concept of multipurpose inland residential platforms used on European waterways	147
22. SMOLNIK PAWEŁ	
Assumption of state policy concerning inland waterways in Poland	154
Miscellaneous	161
23. HĄCIA EWA	
The phenomenon of increasing concentration of tourism in Polish seaside regions	163
24. KIJEWSKA MONIKA	
A graphical model to determine the influence of surface currents on small objects immersed in water	170
25. WÓJCIK ANNA, PIETRZYKOWSKI ZBIGNIEW	
Methods for building a knowledge base for automatic communication in shipping	176
Technology profile	181
26. CHYBOWSKI LESZEK, KUŹNIEWSKI BOLESŁAW	
Utilising water wave energy – technology profile	183

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Editorial preface

Leszek Chybowski

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Dear Readers,

It is our great pleasure to present the 47th issue of the Scientific Journals of the Maritime University of Szczecin. This edition features the latest findings and research in the area of transport engineering, maritime navigation and marine engineering.

Articles in the Marine Technology and Innovation section include studies on the influence of marine power plant damage on the environment, fire safety, diagnostics of technical structures, using simulations to analyse the functioning of ship boilers as well as numerical analyses of the hydrodynamic characteristics of ducted propellers.

The Navigation and Maritime Transport section includes articles addressing the use of satellite navigation systems, dynamic optimisation of safe ship trajectory, state-of-the-art techniques and tools for processing navigation data as well as navigation in emission control area zones.

The section entitled Transportation Engineering includes studies addressing inland transport, benefits of using liquefied natural gas fuel in the urban transport, concepts on the protection of the internal market in road transport in European Union countries.

I would also like to take this opportunity to inform you that the Scientific Journals of the Maritime University of Szczecin has been listed in the Emerging Sources Citation Index (ESCI) in the Web of Science™ Core Collection, which was launched in 2015. This demonstrates that our activity in the arena of scientific publishing have been recognised by Thomson Reuters specialists. This is a great honour and an important mark of quality reflecting the efforts we have made to upgrade our quarterly journal. I wish to express my gratitude to the university authorities for their support as well as appreciation for the engagement of my colleagues, members of the scientific board and reviewers.

We strongly encourage authors to submit their articles and readers to provide feedback. In order to access the online version of this issue along with archived editions please visit our website <http://scientific-journals.eu/>.

Leszek Chybowski, DSc PhD CRP
Editor-in-Chief



Marine Technology and Innovation

Analysis of energetic system failures of Polish fishing fleet vessels and their impact on the environment

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Key words: fishing, fishing cutters, failures of energetic system, environmental pollution, vessel monitoring system, risk of collision

Abstract

An analysis of the failures occurring in the energetic systems of Polish fishing cutters, covering the years 1999–2012, is presented in this paper. The structural age, size and number of Polish fishing cutters is also indicated herein. The effect of the failures on the marine environment has been assessed, taking into consideration a presumed fuel spillage depending on fish catch volume and an analysis of the biodegradability of various fuels. The subject of the analysis also includes the damage impact of transponders cooperating with a vessel monitoring system (VMS) on an increase of the risk of collisions between other offshore industry objects and fishing vessels.

Introduction

According to officially used terminology, the term ‘fishing vessel’ includes all fishing vessels regardless of their size. This analysis maintains the former classification of fishing vessels into open and closed-deck fishing boats and fishing cutters. Fishing boats include vessels with an overall length up to 15 meters, while fishing cutters are craft over 15 meters in length.

Following implementation of the European Union directives, the Polish Baltic fishing fleet has been subject to constant reduction.

Accession of Poland to the European Union in 2004 decisively affected Polish Baltic sea fisheries. The fishing fleets belonging to the EU Member States are too large compared with the available stock of fish. Therefore, ways to reduce the size of a fleet, and also to establish time-limits for when fishing vessels may catch specific fish species have been sought. Implementing the European Union directives, the Polish Baltic fishing fleet has been subject to constant reduction.

A particularly large number of fishing cutters of the Polish fishing fleet have been reduced, that is vessels whose length exceeds 15 m. Figure 1 presents the number of fishing cutters since the accession of Poland to the European Union divided into

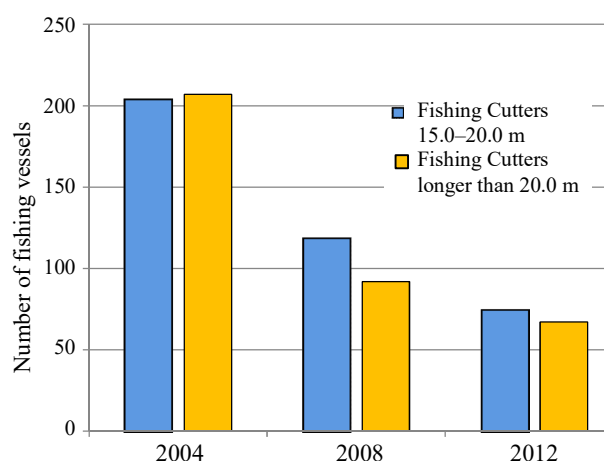


Figure 1. Number of fishing cutters of the Polish Baltic fishing fleet from 2004 to 2012 (Rajewski & Behrendt, 2008; Behrendt, 2013)

two groups according to the length of the ship's hull: fishing cutters of length from 15 to 20 m and those exceeding 20 m.

The changes in the number of fishing cutters, without any division of the ship's hull length, for the analyzed period 2004–2012 are shown in Figure 2.

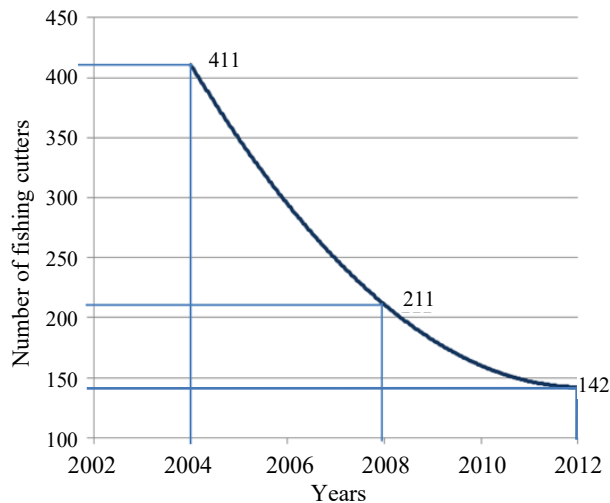


Figure 2. Total number of fishing cutters of the Polish Baltic fishing fleet in 2004–2012

As it appears from the analysis carried out using the results presented in Figures 1 and 2, major reductions in the number of fishing cutters occurred in the segment with length exceeding 20 m. Out of the fishing cutters group, the length of which equals from 15 to 20 m, 95% were constructed in 1955–1970. The newest vessels in the amount of 3 units were constructed in 1991–1992 in Odra Shipyard in Szczecin (Rajewski & Behrendt, 2008; Behrendt, 2013). The situation is slightly better in the case of fishing cutters of length exceeding 20 m. Having analyzed the fleet size in 2012, in that group of the fishing cutters, 50% of the vessels have been in operation for more than 25 years (Rajewski & Behrendt, 2008; Behrendt, 2013).

Owners of fishing vessels also purchase fishing cutters operated by other countries' fleets, such as Germany, Denmark, Holland and Russia. However, these are individual cases, and the age of the purchased fishing cutters ranges from 20 to 30 years. The age structure of the Polish fishing cutters, as of 2012, whose length exceeds 15 m, is presented in Figure 3.

Vessel age can affect the number of failures. Damage to machines and equipment comprising the energy systems of fishing cutters may cause the release of petroleum products (fuels, lubricating and hydraulic oils) to the water environment, creating

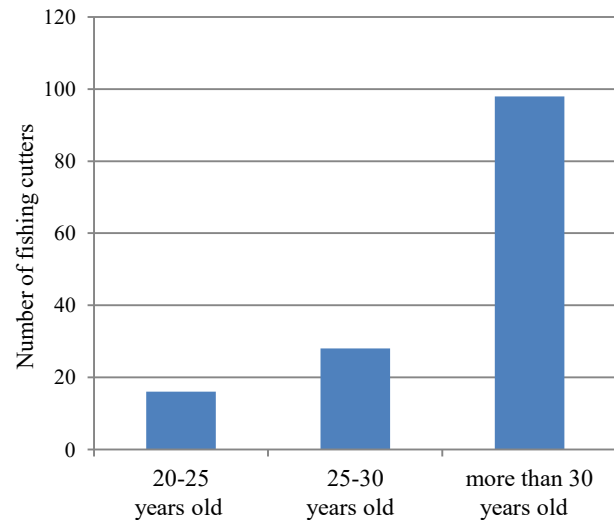


Figure 3. Structural age of the Polish fishing fleet

a risk to biological life. Failures which result in the sinking of a ship are extremely dangerous.

Failures that occurred in the years 1999–2012 have been considered. Energetic system failures are divided into the following types: main engine, auxiliary systems and machinery, main engine shafting and propeller, and finally, propeller fouled by fishing gear. Source materials used in the analysis included documents from the Maritime Court of Appeal in Gdynia, Maritime Court units operating at the Regional Courts in Gdańsk, Gdynia and Szczecin, materials from the insurance company TUiR Warta SA – its branches in Szczecin Świnoujście, Koszalin, Kołobrzeg, Darłowo, Kamień Pomorski and Dziwnów, and from the Maritime Office in Słupsk.

Failures of fishing cutters

The list of failures of fishing cutter energetic systems divided by the year 2012 and type of failure is presented in Table 1.

Among the fishing cutters, the greatest number of failures occurred to the main engine counted together with auxiliary systems and machinery serving the main engine. These two types of failure combined made up over 48% of all failures reported by fishing cutters in the years 1999–2012. Propeller fouling by fishing gear – nets and lines – was most significant in this class of fishing vessels. In total, 81 failures corresponded to nearly 32% of all failures in that period.

The figures in Table 1 are illustrated in the bar chart below (Figure 4).

Table 1. Energetic systems failures in fishing cutters (Materials of TUiR Warta SA; Materials of the Marine Court of Appeal in Gdynia; Materials of the Maritime Court at the Regional Courts in Gdańsk; Materials of the Polish Register of Shipping; Materials of the Maritime Office in Slupsk)

Year	Type of energetic system failure				Total
	Main engine	Auxiliary systems and machinery	Shafting and propeller	Propeller fouled by fishing gear	
1999	6	4	6	6	22
2000	6	3	–	8	17
2001	–	5	2	8	15
2002	5	8	7	2	22
2003	9	12	7	10	38
2004	6	2	5	8	21
2005	8	2	4	8	22
2006	5	3	3	9	20
2007	2	3	2	5	12
2008	3	4	3	4	14
2009	2	5	3	5	15
2010	4	4	2	3	13
2011	3	5	3	3	14
2012	2	3	3	2	10
Total	61	63	50	81	255

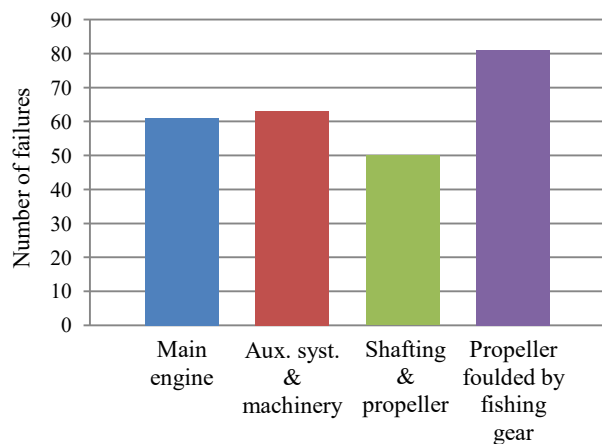


Figure 4. Number of energetic system failures in fishing cutters

Failures of VMS transponders

VTS is a satellite system for monitoring fishing vessels. Fishing vessels must be equipped with transponders. Satellite data is monitored and stored by the Polish Fisheries Monitoring Centre. Under the agreement signed with the Border Guard on the exchange of information regarding ships staying in Polish maritime areas, the data is provided to the Automated Radar Surveillance System of Polish Maritime Areas.

Although the VMS system serves to monitor fisheries, precise data on vessel position was used to

carry out rescue operations in the case of fishing vessel energy system failures and collisions with other cutters or offshore industry objects (mainly commercial vessels).

A mathematical model was developed by the Maritime University of Szczecin, which allows assessment of the number of collisions and damages to the fishing vessels (Gucma et al., 2008).

Simulation tests with the use of the developed model were conducted using the stochastic model of navigational risk assessment based on the Monte Carlo method. Simulation time may be accelerated, which allows us to obtain statistically stable results. As far as the statistics of accidents are concerned, most of the damage is caused by the collision of vessels. Therefore, it was decided to simulate situations covering these types of accidents.

The tests were conducted in two stages:

- firstly, excessive close-ups were computed (less than 0.1 Mm) between fishing vessels and commercial vessels; an average number of such situations equaled to 1800;
- the second stage referred to the calculation of collision feasibility; the calculation was based on the grounds of the number of identified collisions and excessive close-ups between fishing vessels; the result is $3.2 \cdot 10^{-3}$.

At the following stage a simulation was carried out. The result of which are provide a number of collisions within a year and a volume of petroleum products spilled. In order to obtain statistically stable conditions, it was assumed that the simulation period was 70 years.

As a result of the simulation, an average number of simulated incidents was obtained which amounted to 5.73 collisions/year.

Vessel collisions may result from incorrect own or external navigation. They may happen in ports, at roadsteads and in fisheries. In the case of fishing vessels, the collisions may happen due to the loss of vessel maneuverability as a result of winding fishing gear, lost and remaining in the depths, on the propeller or propeller shaft. Also, a large number of vessels simultaneously being at the fishery and catching fish limits their maneuverability and is the reason for higher collision feasibility.

Figure 5 presents the number of transponder failures noted and reported by the Polish Fisheries Monitoring Centre to fishing vessels owners between 2011 and 2014 (Materials of The Center of The Monitoring of Fishery in Gdynia).

As it may be noted in Figure 5, the number of damages in the analyzed period (2011–2014)

varied in the range of 75 to 103. The transponders are installed on around 480 vessels (Rajewski & Behrendt, 2008; Behrendt, 2013).

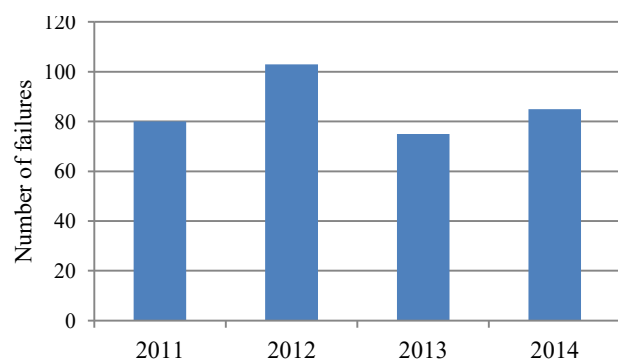


Figure 5. Number of transponder failures installed on fishing vessels

Environmental pollution due to fishing cutter failures

Failures in the energetic systems of the fishing fleet are a potential source of marine environment pollution due to spills of oil products, such as fuels, lubricants and hydraulic oils. Environment pollution is most likely to happen in the case of the propeller being fouled by ropes or nets. As a result, the stern tube becomes unsealed and lubricating oil is released into the sea; when the controllable pitch propeller is thus affected – the sealing between the blades and the hub is damaged and consequently, hydraulic oil is spilled (Materials of TUiR Warta SA; Materials of the Marine Court of Appeal in Gdynia; Materials of the Maritime Court at the Regional Courts in Gdańsk; Materials of the Polish Register of Shipping; Materials of the Maritime Office in Słupsk).

There were 11 spills noted within the examined period caused by fishing gear that fouled the propeller. One boat sinking in a harbor was reported. Its reason for sinking was the unsealing of the stern tube through which water flooded into the unmanned boat in the night.

Similarly, the marine environment may be threatened by failures of the main engine or its auxiliary systems or machinery. A failure of boat propulsion makes the craft unable to be maneuvered. This in turn, in specific operating conditions, such as heavy traffic of the ship's maneuvering in a restricted area and fishing in the vicinity of shallow waters, may result in collisions.

Immediate actions which occur after a collision results in a damaged hull, include discharging oily water into the sea. In extreme cases the ship involved in the collision may sink which often leads to fuel oil

and lubricant spills from the wreck. In the examined period, six collisions and one sinking were recorded, all resulting from main engine or auxiliary system/machinery failures.

A spillage area is assessed on the basis of vessel fuel tank volume. An analysis of real objects allowed the development of a formula for fuel amount in the tanks of fishing vessels depending on the length of the vessel (Gucma et al., 2008):

$$M_p = 0.2026 e^{0.1938L} \text{ [tons]} \quad (1)$$

where: L – vessel length [m].

Spilled fuels are subject to biodegradability, referred to as degradability caused by biological activity, in particular by enzymatic reactions leading to the change of the fuels chemical structure. In the case of fishing vessels, petroleum fuels are commonly used. Due to increasingly stricter regulations on air protection against the emission of harmful exhaust components, creating a special zone on the Baltic Sea and the EU regulations on alternative fuels, there is ongoing research regarding the use of biofuels for combustion engines of fishing vessels (Report, 2012; Klyus, Behrendt & Rajewski, 2013).

Biofuels are characterized by significantly higher biodegradability than petroleum fuels. Biodegradability efficiency in water is tested upon 28 days, as a percentage of fuel decomposition.

Table 2 presents the results of the laboratory tests of the selected petroleum fuels.

Table 2. Biodegradability of selected petroleum fuels (Zhang & Peterson, 1998; Speidel & Lightner, 2000)

Fuel	Biodegradability [%]
Gasoline (91 octanes)	28
Residual fuel (Bunker C)	11
Refined rapeseed fuel	78
Refined soya fuel	76
Rapeseed methyl ester	88
Sunflower methyl ester	90

As it may be noted during the analysis of the data in Table 2, petroleum fuels are characterized by low biodegradability – between 10 and 30% upon 28 days. The biodegradability of the methyl esters of plant oils is 3–9 times higher within the range 15–90%. Plant oils have slightly lower biodegradability than methyl esters.

Cyto Culture Inc. conducted the research aimed at demonstrating the impact of methyl esters from plants on aquatic organisms. A basic parameter allowing for the results interpretation is the so called LC50, namely the compound concentration causing

50% mortality of the population. The results of the ecotoxicological tests are presented in Table 3 (Zhang & Peterson, 1998).

Table 3. Ecotoxicological tests results (LC50)

Species tested	Fuel	Result
Larval stage of fish	Biodiesel 80	578 ppm
Menidia Beryllina	diesel	27 ppm
Larval stage of shrimp	Biodiesel 80	122 ppm
Mysidopsis Bahia	diesel	3 ppm

The ecotoxicological tests were carried out on larval forms of fish and shrimp due to their higher sensitivity to ambient conditions as compared to adult forms.

It may be stated on the basis of the data in Table 2 that although biodiesel is not completely harmless to fish and shellfish larvae, it is 20 to 40 times less harmful than petroleum fuels.

Taking into consideration the biodegradability, the reduced emission of harmful exhaust components and the results of the ecotoxicological testing, it is advisable to use biofuels for fishing vessels combustion engines, in particular due to their operation in a special zone such as the Baltic Sea.

Conclusions

In the years 1999–2012 there were reports on as many as 255 failures in fishing cutters operating in the Baltic Sea from Polish ports. Among the four examined types, or groups, of failures relating to the energetic systems of fishing cutters, the fouling of the propeller by fishing gear is the most frequent reason. Figure 6 presents an example of the damage to the propulsion system of a fishing vessel



Figure 6. Therope wound on a line of shafts

which limits operation of the vessel. The damage was caused by a rope wound on a line of shafts.

The damage presented in Figure 6 resulted in the need to haul the vessel to a port by a second cutter fishing nearby. A fishing line screwed into the stern tube seal of the fishing vessel is presented in Figure 7. Oil spillage was a result of the situation.

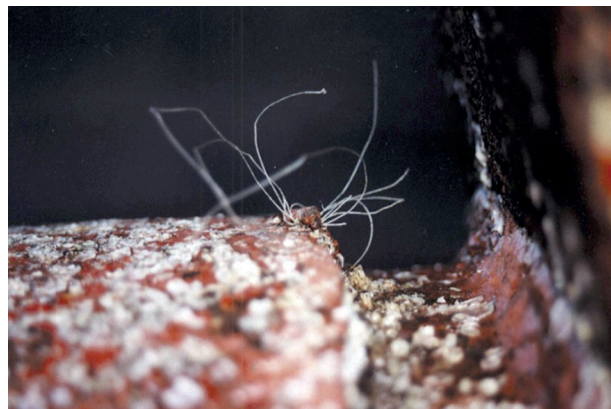


Figure 7. Nylon fishing line of a fishing net line screwed into the stern tube seal

A total of 81 such failures make up over 32% of all failures. 11 cases of marine environment pollution were reported to have been caused by oil spillage. The direct reason was either a leak of the stern tube or due to the controllable pitch propeller blades mounted to the hub, line or net fouling the propeller. The two fishing craft sinking incidents reported also caused oil spills. The substantial share of failures caused due to a propeller fouled by lines or nets results from the specific character of fishing cutter operation connected with running out and hauling in fishing gear while sailing at slow speed or a drift, often at high seas.

Notably, in the case of 124 failures of the main engine or its auxiliary systems and machinery, 48% of all the examined cases, the age of cutters was a significant factor. More than 87% of the failures occurred to cutters built more than 25 years ago.

Failures of the main engine or its auxiliary systems and machinery caused six collisions and one sinking. The advisability for using biofuels has been shown in relation to the supply of fishing vessel engines due to their high biodegradability (3–9 times higher than petroleum fuels) and due to 20–40 times lower toxic effect on live organisms than petroleum fuels. As far as the implementation of a new satellite control system, VMS, is concerned, its possibilities and functions in relation to preventing collisions and its application during rescue operations has been presented. An average

number of simulated collisions of fishing vessels was determined at the level of 5.73 collision/year for the Polish fishing fleet.

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Simulator of a nitrogen purging fuel gas line system of the main propulsion boiler on liquefied petroleum gas ships

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Abstract

Dynamic development of Programmable Logic Controller (PLC) technology and *Supervisory Control and Data Acquisition* (SCADA) software has resulted in their widespread usage in integrated systems of automation, becoming one of the main directions of ship automation. This change justifies the need to improve the training of future crews on simulators built with the use of PLC and SCADA technologies. This paper presents a simulator prototype for selective processes of a main-propulsion boiler's fuel-gas-line nitrogen purging system, applied in LNG (liquefied natural gas) ships. Control algorithms and appropriate schematic diagrams of the LNG fuel system of these processes were also presented. A Versa Max Micro-series PLC and an InTouch 9.0 PL SCADA software were applied in construction of the simulator. As a result of simulations, a visualisation of different states of fuel line in the form of screenshots was included. Finally, the paper contains a concept for simulator development based on hardware (sensors and actuators) without significant changes in existing software; further development will provide the simulator with more similarities to a real ship system.

Introduction

Dynamic development of the Programmable Logic Controller (PLC) microprocessor technique brought a new trend in design of industrial automation systems. The technology is based on a programmable microprocessor unit performing a real-time-control algorithm. PLCs can be found in wide application in industry due to numerous advantages, as below:

- programming ease and speed;
- ease of changes in the control algorithm without hardware modification;
- various kinds of inputs/outputs (binary, analogue, dedicated);
- the ability to build a network of PLCs, allowing for complex, distributed control systems;
- the ability to fit the PLC in modules, making mutual communication via networks possible (Internet/Intranet).

Simultaneously with the progress of PLC technology, there has been development of industrial

software known as Supervisory Control and Data Acquisition (SCADA), making possible an integrated environment with an easy application visualisation, control, and monitoring of industrial processes. The above presented advantages of PLC and SCADA brought about their widespread use in integrated automation systems of ships; as a result it is necessary to improve the training of future crews. It seems appropriate to build, for training purposes, simulators of processes occurring in the engine room with use of PLC and SCADA technologies. This paper presents the concept of the simulator, which allows for the selected control sequences of the main propulsion boiler. On this base, the prototype of system was built, which serves as a didactic stand for the Chair of Automation and Robotics, Maritime University of Szczecin.

Subject of simulation

As the subjects of the simulation were chosen, the sequences applied in control of the main-propulsion

boiler of a LNG ship, destined to transport of liquefied natural gas (Ship Manual, 2003; Mitsubishi Heavy Industries, 2004). Selected were two of four sequences of nitrogen purging of the fuel gas line. Nitrogen purging is applied in two-burner boilers of main propulsion LNG ships except where fuel oil (FO) gas, being a product of cargo evaporation, is burned – Boil-off Gas (BOG) (Ship Manual, 2003; Mitsubishi Heavy Industries, 2004).

Sequences of purging of the fuel gas line are realised by Burner Management System (BMS) (Ship Manual, 2003). They play an important role in the process of a ship's exploitation because removing them after shutting off the gas burner residuals of gas from boiler fuel system is necessary to prevent explosion.

The sequence consists of:

- nitrogen purging of the gas header to ventilation mast;
- nitrogen purging of the gas header and gas burner to furnace;
- nitrogen purging of the gas burner to furnace;

d) nitrogen purging of the master line to ventilation mast.

The subjects of the simulation in this paper are sequences a) and b).

The system diagram of nitrogen purging the gas header is shown in Figure 1.

The starting signal for this sequence is the signal of closing the boiler gas valve (BGV). After closing of this valve, the control system realises the sequence according to the algorithm, shown in the block diagram in Figure 2.

The second item implemented in the simulator sequence is nitrogen purging of the gas header and gas burner to the furnace. A diagram of the installation corresponding to this sequence is shown in Figure 3.

The aforementioned sequence can be executed only when, if all gas burners do not work, gas valve G1 is closed and at least one FO burner works. The start of the sequence begins with a moment of shutting off the last basic gas burner (i.e. closing of G1 valve). The sequence is executed according to the algorithm presented in Figure 4.

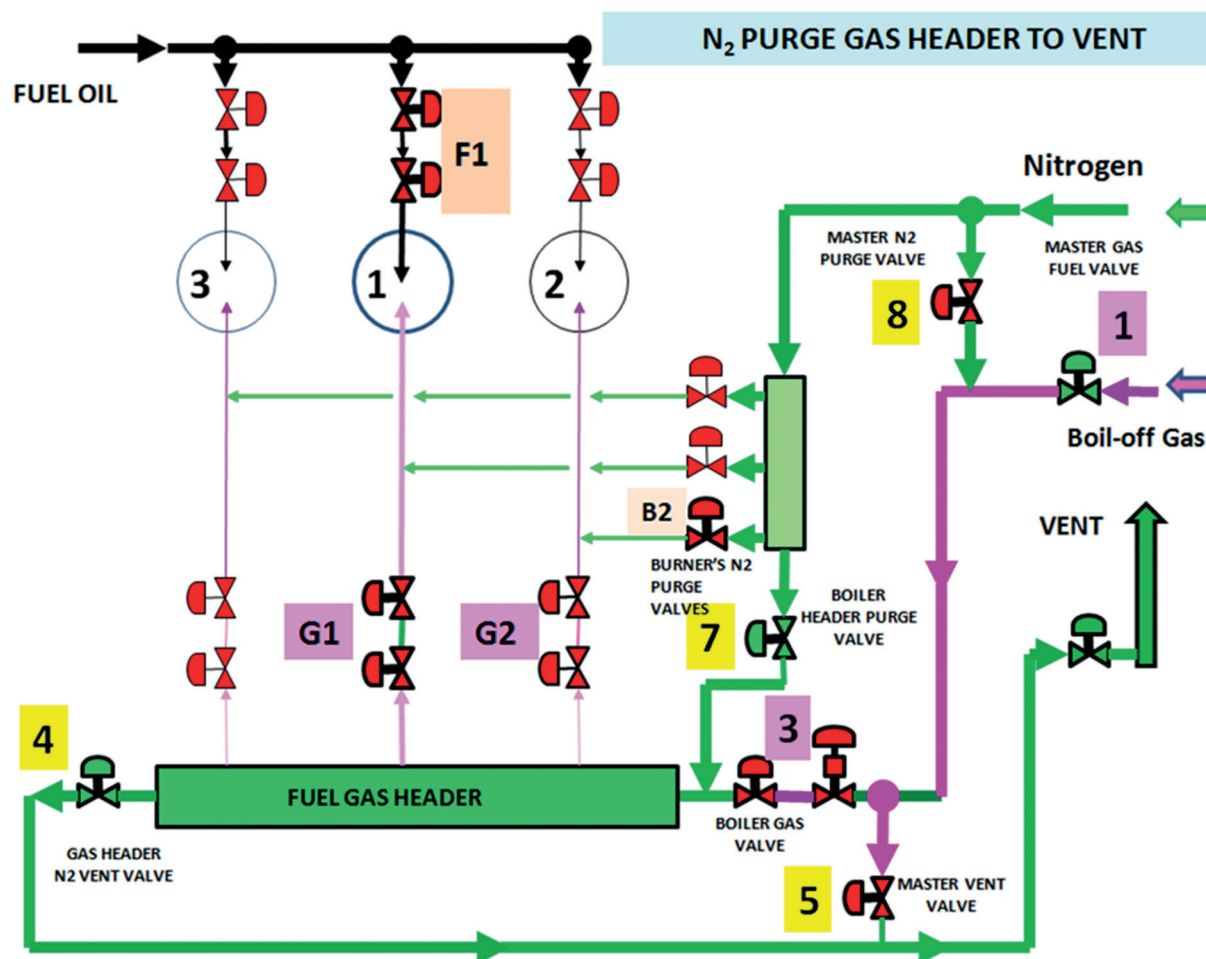


Figure 1. Nitrogen purging gas header to ventilation mast (Ship Manual, 2003)

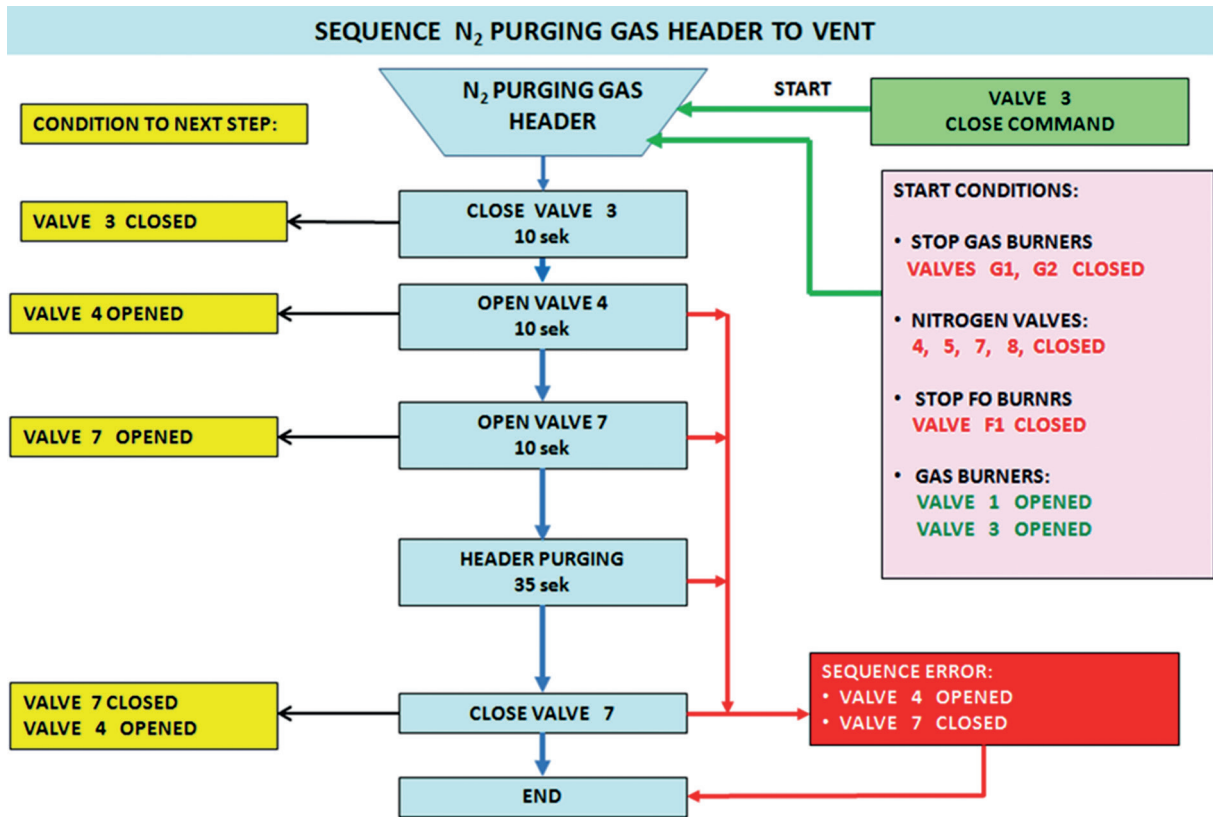


Figure 2. Algorithm of nitrogen purging of the gas header to ventilation mast sequence (Ship Manual, 2003)

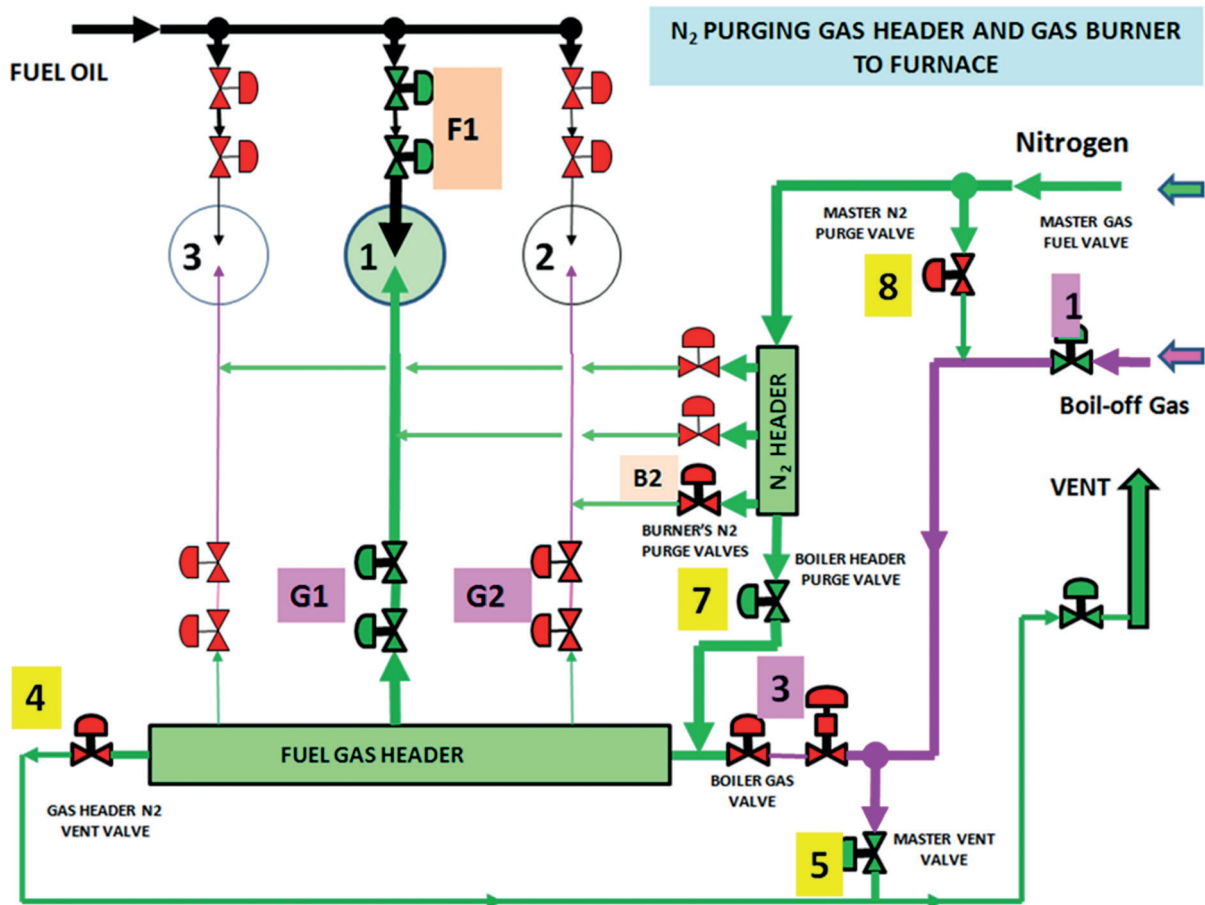


Figure 3. Nitrogen purging of the gas header and gas burner to furnace (Ship Manual, 2003)

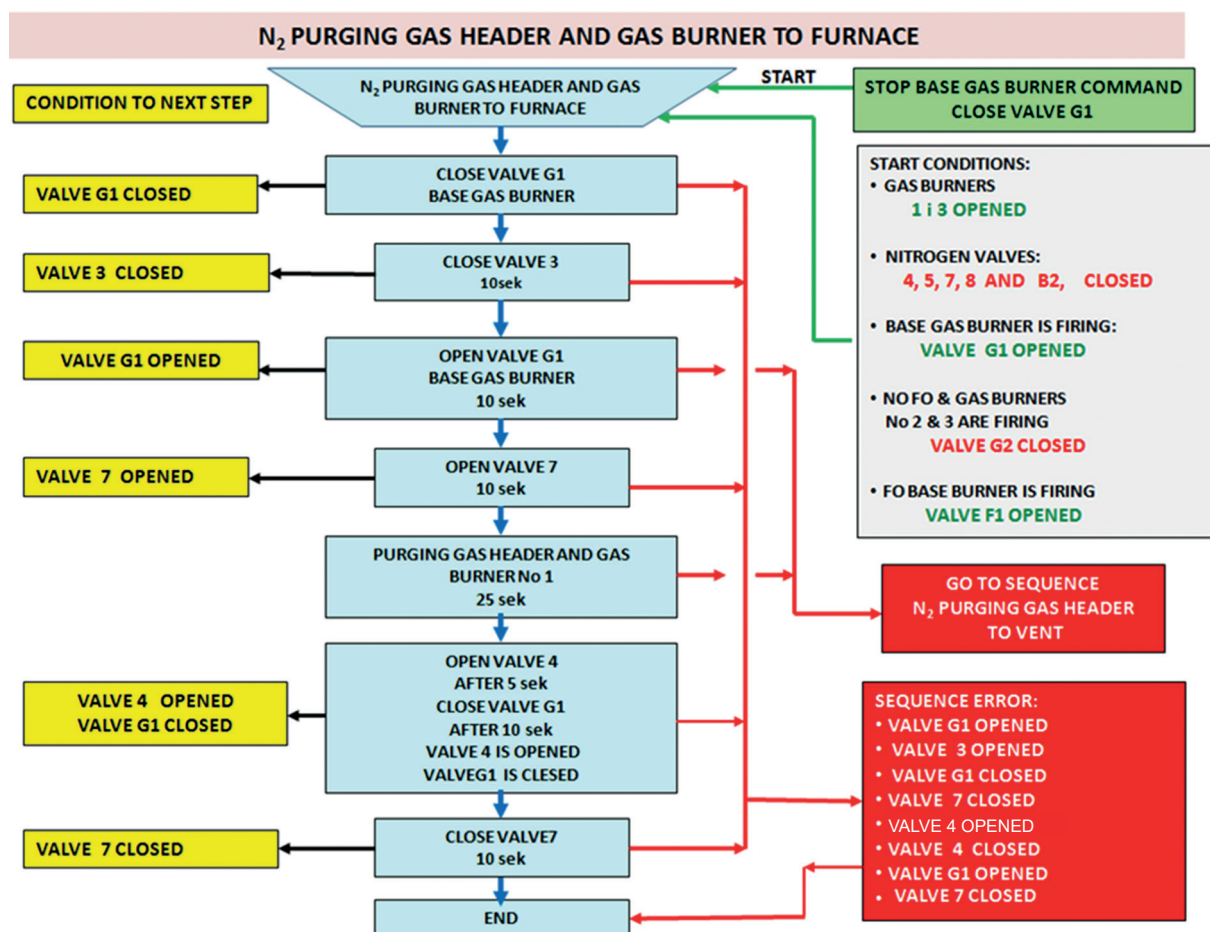


Figure 4. Algorithm of nitrogen purging of the gas header and gas burner to furnace sequence (Ship Manual, 2003)

Description of the simulator

The simulator of the boiler master line purging processes is shown in Figure 5.

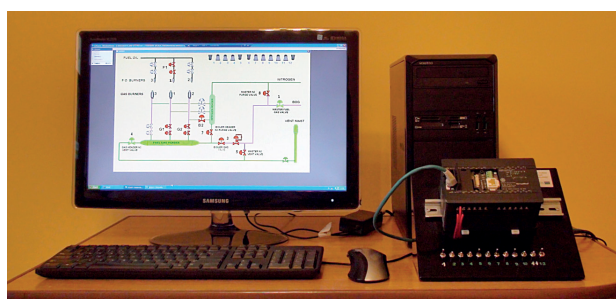


Figure 5. Laboratory stand dedicated to simulation of the boiler master line purging processes (Matyszczak, 2014)

The laboratory stand consists of a PC-type computer with an attached PLC-type Versa Max Micro IC200 UDR 020-200 connected with 12-bit binary signals input unit (GE Fanuc Automation, 2002). Simulated are sequences described in chapter 2, namely:

- nitrogen purging of the gas header to ventilation mast;

- nitrogen purging of the gas header and gas burner to furnace.

For the aforementioned sequences, control programs were prepared that use ladder diagrams language and are implemented in PLC. A visualisation of the simulated processes is performed with SCADA-type Intouch software (Astor, 2005).

The binary signals input unit was built with use of 12 switches, allowing application to the controller's input control voltages 0 V/24 V DC. It is used to generate the start signal (Key #1) and confirm opening/closing of the valves (Key #2, Key #12).

Simulated sequences are visualised on the top of the screen. To make the operation of the simulation easier, at the top of the screen the system of input unit keys, which must be preset before starting the simulated sequence, is shown. During execution of particular steps of the sequence, information is displayed on the screen, including which signal of confirmation (Key #2, Key #12) should be used.

After input of a confirmation signal, the displayed text disappears. An opened valve icon is plotted in green colour, whereas closed are in red. The beginning of the opening/closing of the valve

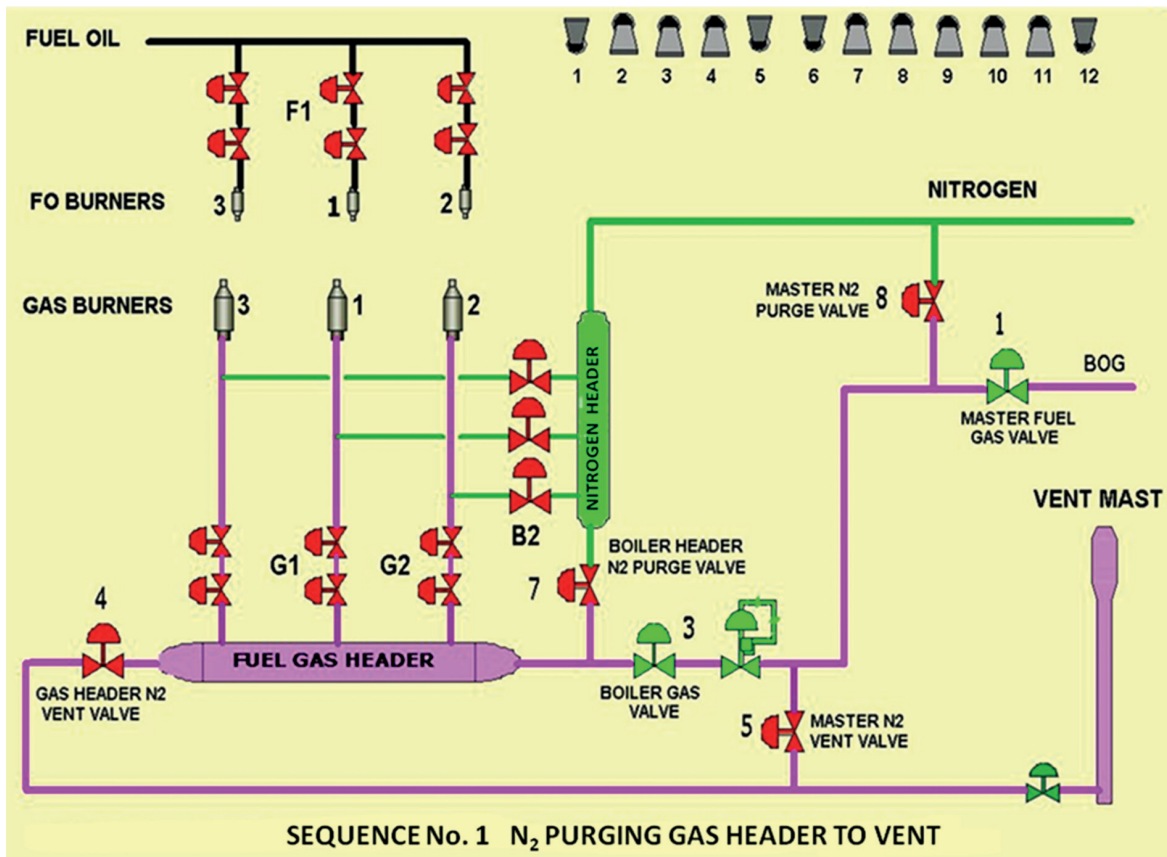


Figure 6. Screenshot taken before the start of nitrogen purging of the gas header to ventilation mast sequence

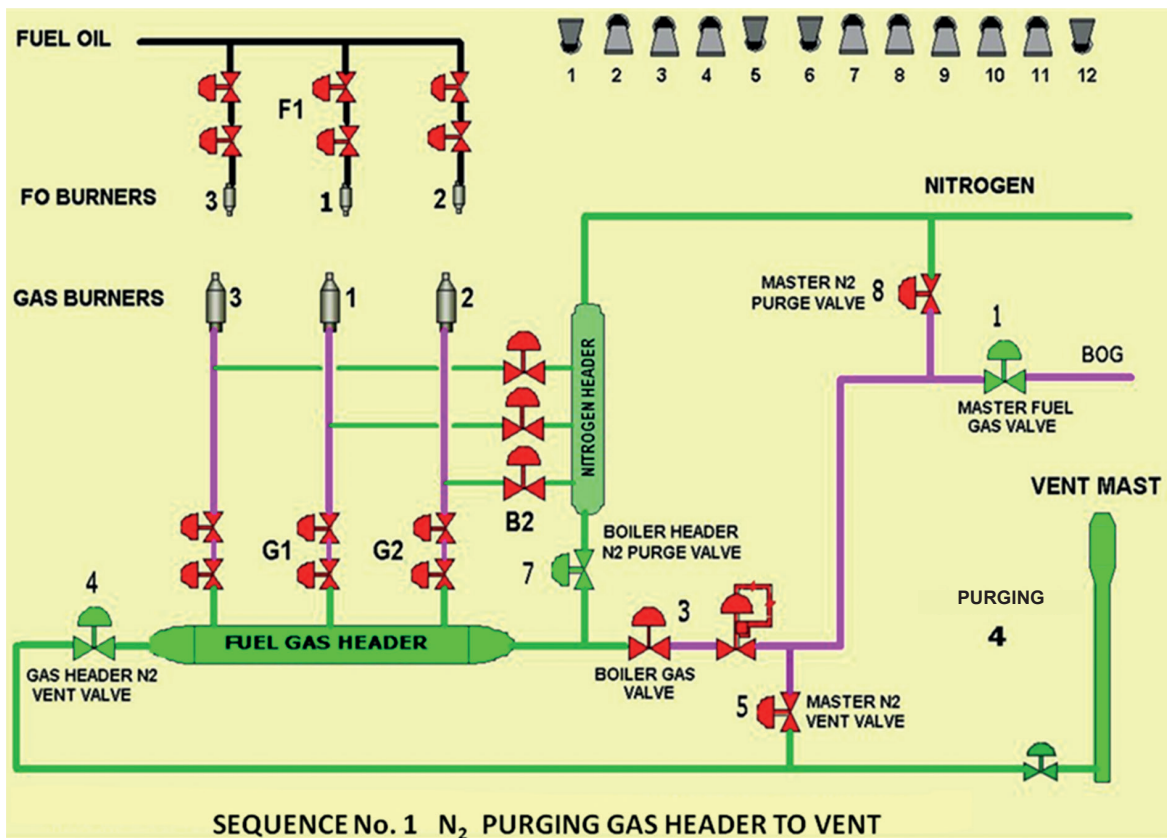


Figure 7. Screenshot taken during execution of nitrogen purging of the gas header towards ventilation mast

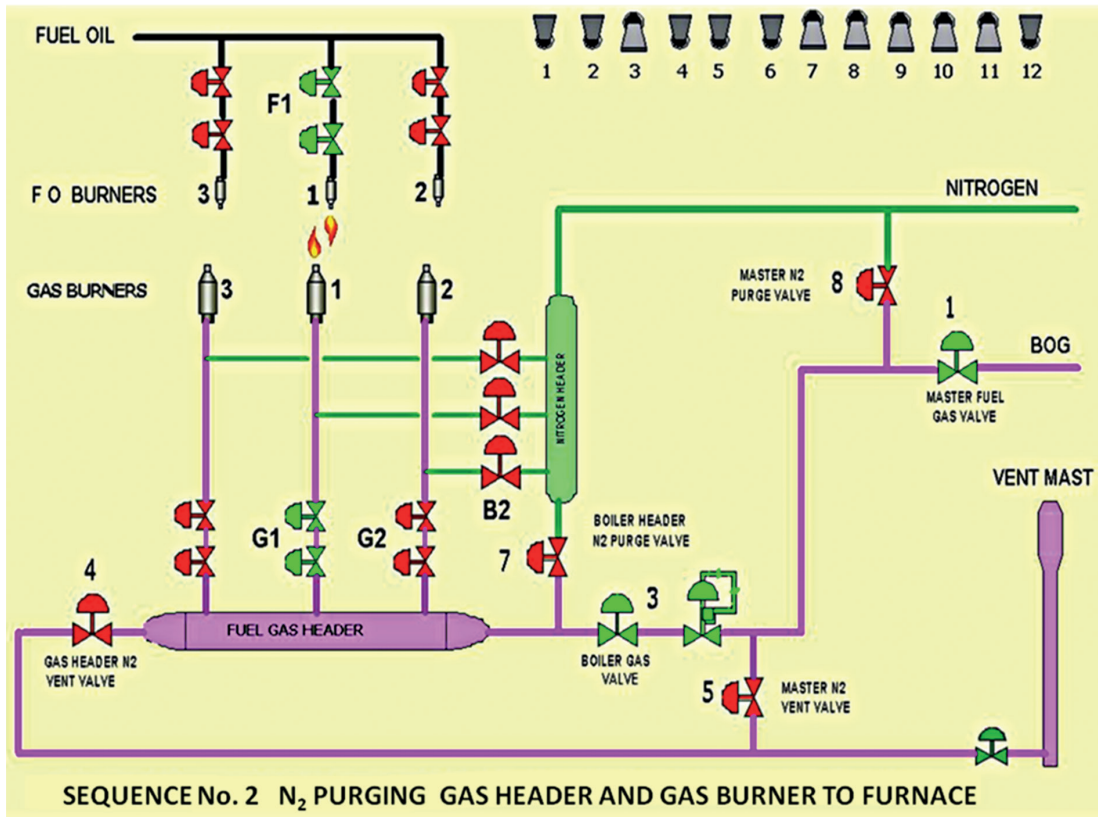


Figure 8. Simulation of nitrogen purging of the gas header and burner to furnace – showing the state of installation before start of sequence

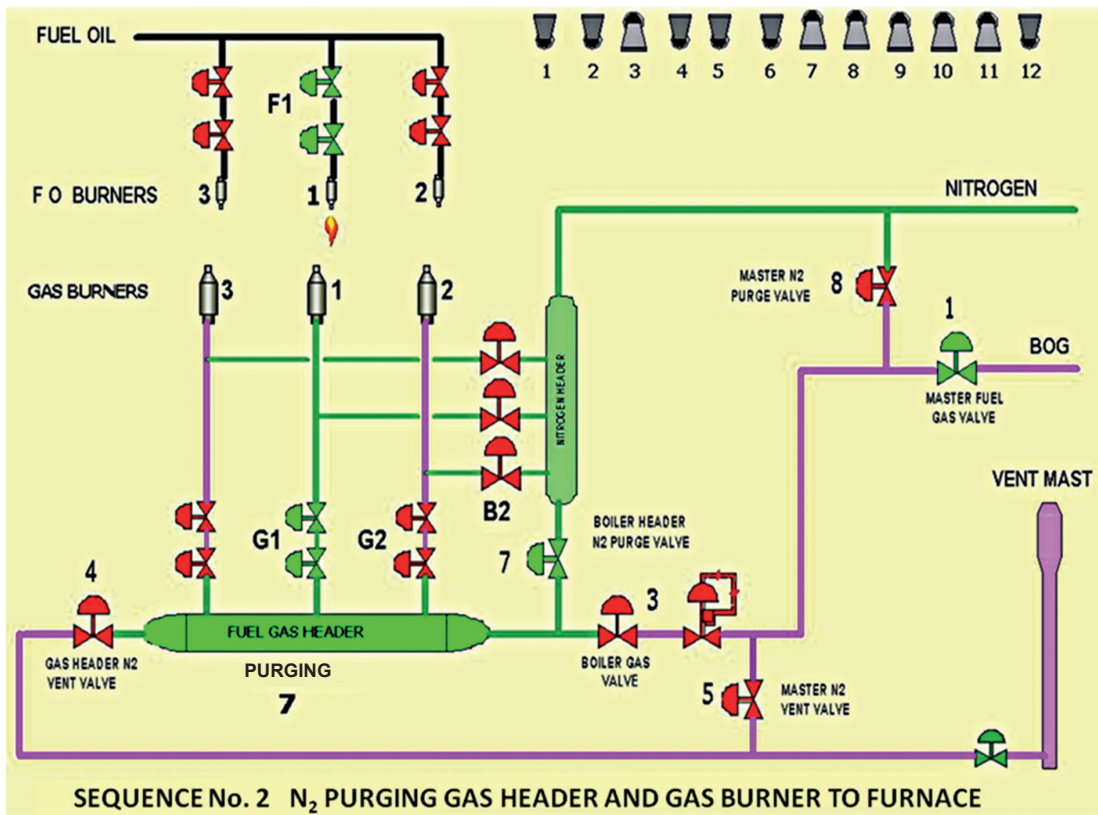


Figure 9. Simulation of nitrogen purging of the gas header and burner to furnace – state of installation during execution of sequence

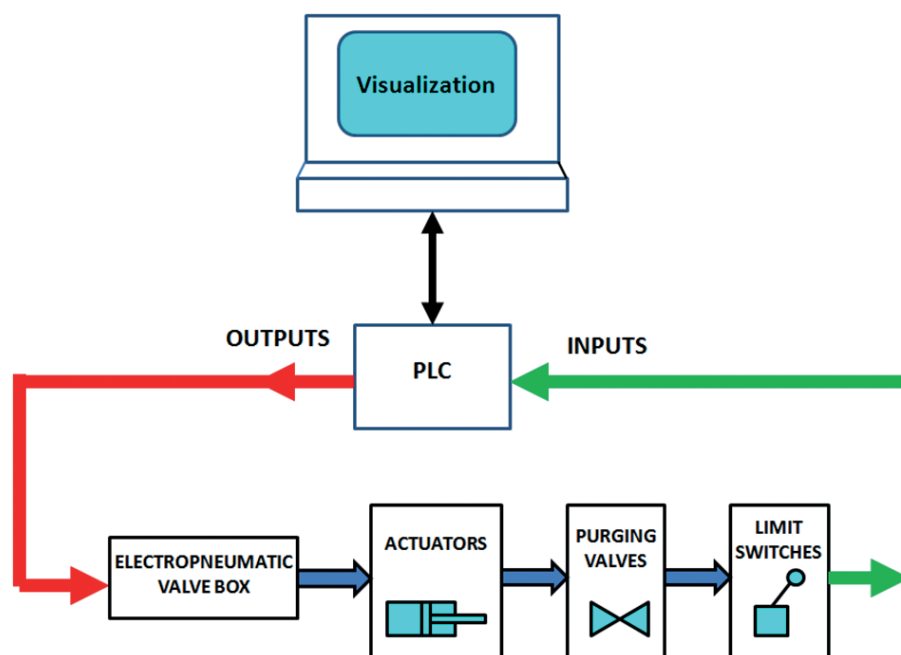


Figure 10. Concept development of the simulator

is indicated by flashing of the icon, and after confirmation of opening/closing, the colour of valve icon stop flashing.

Another variable is the colour of pipes, depending on the kind of flowing gas (BOG/ nitrogen).

Figures 6 and 7 present the screenshots taken for simulation of nitrogen purging of the gas header to the ventilation mast, showing the states of valves and installation before the sequence start and during the purging process.

Screenshots taken before and during nitrogen purging of the gas header and burner to furnace are shown in Figure 8 and Figure 9, respectively.

Conclusions

This paper describes a prototype of a simulator that executes selected control sequences of the main propulsion boiler of a LNG ship. The application of PLC technology and SCADA software and the original applied algorithms conforms the described simulator to real systems. The simulator enables illustration of selected control sequences of fuel gas line nitrogen purging and understanding the role of PLCs in computer automation systems. It should be highlighted that there are many possibilities of

development of the presented simulator. One of them, which does not require significant changes in software, is connection of appropriate sensors to inputs and actuators to the outputs of PLC, shown in Figure 10.

The concept in Figure 10 is the subject of further work of the author.

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The use of text models in the formation of heuristics to solve tasks of diagnosing technical objects

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Abstract

This paper describes research related to the use of heuristics in diagnostic tasks of complex technical objects. To build heuristics, the use of text models for technical objects is proposed. Therefore, this paper examines output methods of heuristics from text models and their transformation into logical formulae suitable for use in diagnostic algorithms. Analysis has been carried out for tasks solved during diagnostics, and methods of using heuristics in certain tasks have been reviewed. It is proposed to use heuristics for decision making while implementing certain algorithm steps of monitoring tasks for diagnostic parameters that are solved during diagnostics.

Introduction

The task of diagnostics for complex technical objects (*STO*) is actually in the sphere of naval technologies, because examples of such objects are ships themselves or power units of large cargo ships. The task of diagnostics involves the detection of malfunctions which start taking place or are forecasted, their localisation and further elimination. We can accept that *STO*, in general can be described by some mathematical model, adequate for processes taking place in *STO*, so that we can solve the aforementioned tasks in the framework of the model.

In the framework of this work, the task of diagnostics is reviewed as a composite task, consisting of monitoring diagnostic and functional parameters, allowing the detection and localisation of possible malfunctions as well as the task of recognising and fixing the detected malfunctions. The monitoring task involves checking the parameter values in one or more sequences. As *STO* are large and complex, in the framework of one monitoring cycle it is impossible to check all possible parameters. Therefore, the

task of forming a monitoring strategy arises, which would enable the detection of malfunctions at an early stage.

To form the appropriate monitoring strategy, in this work the use of heuristics is proposed, based on diagnosed process text descriptions, using formal means of non-monotone logic. This will allow the development of separate steps for the real-time monitoring strategy, to ensure the strategy is efficient in malfunction detection.

Basic concepts and tasks

There is a wide range of definitions and concepts of heuristics which represent features such as soft asks, and require them to be solved (Michalewicz & Fogel, 2006). To interpret the concept used in this paper unambiguously, let us introduce a definition of heuristics.

Definition 1. Heuristics ($\mathcal{E}r_i$) is a single rule or a system of rules for making a certain decision while solving a task. These rules cannot be deduced within the scope of functional tools or a mathematical

model of task solving, but they represent features of a subject area where the task is solved.

Based on this definition, in order to build a heuristic system, further note das \mathfrak{H} , a certain extended description is needed for a subject area where the task which is solved can be interpreted. This extension must allow analysis and description of the situations which can occur in the object related to the task being solved, and it has to enable entering of changes, occurring within the object, into the corresponding object description. To implement such a description, it is proposed here that text models previously described (Korostil & Korostil, 2012) be adopted. In general, a text model is a text description of technological processes that take place in a complex technical object in the normalised form, in the native language of its user. Let us review the definition of such an object, which will be used in this paper.

Definition 2. A complex technical object (*STO*) is a technical object which does not allow, at least not without difficulties, to build a unified functioning model, which provides a sufficiently relevant and constructive object description, with regard to all possible malfunctions which may occur during its functioning.

Because a text model (TM_i) is a text description of the processes taking place in *STO*, this description is relevant enough to represent processes of functioning (Pr_i) for the correspondent *STO*. To ensure the necessary amount of constructiveness of the TM_i , the model has to provide the following functional possibilities:

- the model TM_i has to be able to be modified in order to represent changes occurring in Pr_i and take place in *STO*;
- the model TM_i has to give the possibility to detect dependencies, not only between directly related parameters from Pr_i , but also indirectly related parameters, as well as to give the opportunity to detect dependencies that could be latent within *STO*;
- the model TM_i has to give the possibility to transform the processes Pr_i or their fragments into a system of logical models which will be written as $\mathcal{L}_i(STO)$.

It is planned, on the basis of the model TM_i [$Pr_i(STO)$], to implement processes for deducing rules or conditions that describe certain heuristics $\mathcal{E}r_i$, which compose the system \mathfrak{H} . Thus, a system of rules for deducing heuristics from TM_i must be built, which will be written as \mathfrak{S} . For this system we have to determine input formulae as well as formulae

obtained on the basis of deduction, which would allow for their interpretational extension, so that these formulae would transform into certain heuristics $\mathcal{E}r_i \in \mathfrak{H}$. Extension of $\mathcal{E}r_i \in \mathfrak{H}$ with interpretations $j(\mathcal{E}r_i)$ will allow us to obtain the necessary rules \mathcal{G}_i , that represent heuristics $\mathcal{E}r_i$. Then, the following correlation can be written:

$$\mathcal{E}r_i = F [\mathfrak{S}_i(L_{i1}, \dots, L_{im}) \& J(\mathfrak{H})] \quad (1)$$

where $\mathcal{E}r_i$ are single heuristics in the diagnostic model of *STO*, \mathfrak{S}_i is a system of rules for transforming L_{i1}, \dots, L_{im} , built on the basis of transformations $\varphi_i(TM_i) \rightarrow L_{ij}$, F is a function that describes the interrelation between $\mathfrak{S}_i(L_{i1}, \dots, L_{im})$ and $J(\mathfrak{H})$, $J(\mathfrak{H})$ is a system of interpretation for certain L_{ij} , from which they obtain the form of $\mathcal{E}r_i$. The system \mathcal{L}_i is oriented towards using a finite area of interpretation for logical variables that is defined by a model $TM_i(STO)$. So, a logical system must be formed on the basis of formal logics, an example of which is non-monotonous logics (Thayse et al., 1990). One of the features of this logic, unlike classical logic, is that it gives rise to formulae which do not have to be valid on infinite sets of their interpretation (Mordechaj, 2005).

Diagnostic tasks that are solved within the diagnostic model (*MD*) have to be able, within their own interpretation of diagnostic tasks, to use the correspondent $\mathcal{E}r_i$. The diagnostic tasks, within the scope of this paper, are the following (Korbic et al., 2002):

- task of monitoring (*Zm*) diagnostic parameters p_i^d and functional parameters p_i^f ;
- task of detecting the appearance of a malfunction in *STO*, which will be written as (*Zz*);
- task of detecting a malfunction not yet manifested in the functioning process of *STO*, (*Zv*);
- task of recognizing the malfunction (*Zr*).

The tasks of withstanding detected malfunctions, or detected factors of their appearance, are not reviewed in this paper because they are related to the tasks solved within the security system of *STO*.

Each of the above-stated tasks *Zm*, *Zz*, *Zv* and *Zr* required the use of its own heuristics $\mathcal{E}r_i$. Heuristics for each task must allow interpretation, consistent with the interpretation of the corresponding task, described by the following relation:

$$J(\mathcal{E}r_i) \& J(Zk_i) \rightarrow J(Zk_i, \mathcal{E}r_i) \quad (2)$$

where Zk_i is one task in a set $\{Zm_i, Zv_i, Zz_i, Zr_i$. In the case of a monitoring task, heuristics $\mathcal{E}r_i(Zm_i)$ takes part in determining the implementation strategy for the corresponding monitoring. In the case detecting the appearing malfunction, heuristics $\mathcal{E}r_i(Zz_i)$ takes

part in identifying the fact of the malfunction occurring. In the case of detecting a malfunction not yet manifested in the functioning process of *STO*, heuristics $\mathcal{E}r_i(Zv_i)$ takes part in the analysis of diagnostic parameters read within the task Zm_i in order to detect changes related to the malfunction which occurred. In the case of recognizing the malfunction, heuristics $\mathcal{E}r_i(Zr_i)$ takes part in recognizing the type of malfunction, if it is unknown and only certain parameters characterizing the malfunction are known. Heuristics $\mathcal{E}r_i$ also takes part in determining the possible ways of affecting the parameters under change to in appropriate values. In this case, we cannot speak in detail about diagnostic parameters as about a separate class of functional parameters.

Solving of basic tasks

Using text models

A text model TM_i is a text description, in the normalised form of *STO* design and processes occurring within *STO*. Using TM_i allows the automation of processes for implementing different tasks which need to be solved during *STO* maintenance. Using TM_i for solving tasks of *STO* maintenance is rational because of the following key features of *STO*:

- periodic modification of *STO*, which is necessary because of the requirement to update resource parameters for system nodes or components;
- inclusion of new elements in *STO* that represent new technological means which can be used during *STO* maintenance;
- carrying out repairs on *STO*, which can lead to some changes in the original set of system components, the design of *STO* and so on.

While performing these changes, the occurrence of critical situations during certain conditions of *STO* maintenance can eventuate. Because $TM_i(STO)$ contains descriptions of all functioning conditions of *STO*, within TM_i it is possible to detect inappropriate values of parameters on the basis of conducting a semantic analysis of TM_i . Thanks to the introduction of semantic parameters σ^i it is possible not only to detect inconsistencies at quality level, but also to estimate their values in numbers (Korostil & Korostil, 2013).

A text model at quality level, or with a certain approximation, can be considered to be an analogue of technical documentation for the corresponding *STO*. To make it possible to perform analysis and modification of $TM_i(STO)$, semantic vocabularies S_C and S_P are used. A vocabulary S_C contains data regarding all components and process fragments

implemented in *STO*, and is a text description of the corresponding components which compose TM_i . A vocabulary S_P contains identifiers of diagnostic and other parameters which are used to analyse the current state of *STO*. A structure of these vocabularies is described by the following relations:

$$S_P = \{p_1^d, \dots, p_n^d\}$$

$$p_i^d < \beta_{i1} * \dots * \beta_{im} > I < P_1 \leq \delta_1, \dots, P_m \leq \delta_m > \quad (3)$$

where β_{ij} is a word from a phrase of text interpretation of the parameter, p_i^d is an identifier of a diagnostic parameter, P_i is a value of the parameter p_i , and δ_i is a boundary value of the parameter p_i^d . A certain value is introduced for p_i^d which, depending on the current value of the parameter p_i^d , will have different text interpretations $j(p_i^d, \delta_{ij})$. For example, within the threshold δ_{ij} the value of parameter p_i^d can have the following interpretation: $[\delta_{ij} \rightarrow j(p_i^d) = \langle \text{excessive value} \rangle]$, another example of interpretation is $[\delta_{i+1} \rightarrow j(p_i^d) = \langle \text{dangerous value} \rangle]$, or $[\delta_{ij+2} \rightarrow j(p_i^d) = \langle \text{unacceptable value} \rangle]$. From these examples it can be seen that within the vocabularies S_P and, respectively, in $TM_i(STO)$, discrete methods of parameters evaluation, described by interpretative extensions, are used.

To implement processes for transferring information regarding changes of values of parameters occurring in *STO*, a system *SMA* is used that transfers the corresponding information in the model TM_i to modify the corresponding text fragments in TM_i . *STO* modification during maintenance is implemented in the following cases:

- in the case of implementing changes in the *STO* system, caused by the replacement of certain system components, conducted by maintenance staff;
- in the case when it is necessary to enter the current data analysed by the diagnostic system;
- in the case of changes occurring in *STO* as a result of external factors influencing the system, which can demand to add new fragments in the text description of the corresponding model TM_i .

In the first case, the maintenance staff enter the corresponding data into the system *SMA*, using different semantic vocabularies S_i , to describe the subject area W_i of an *STO* object. This generates an information stream IP_i and transfers it into the corresponding model TM_i . In the second case, the system *SMA* chooses the necessary text description from vocabularies of S_i type, on the basis of parameter identifiers p_i^d and the values of the corresponding parameters. After obtaining the information, *SMA* generates the corresponding IP_i for the model TM_i . The transfer of

IP_i into TM_i is implemented at the end of the current system work cycle or the work cycle of a monitoring model (SMO), because it may become necessary to make changes in the descriptions of certain parameters in TM_i . If the current parameter values changed at the amount which foresees the change of interpretation description used in TM_i , the system SMA activates the transfer of generated IP_i into the corresponding model TM_i . Synthesis of IP_i and TM_i is implemented corresponding to synthesis algorithms (Korostil, 2012). In the third case, when changes in STO are caused by an influence from external factors on the system, it can eventuate that there are no interpretation descriptions for these factors, which are necessary to describe the corresponding changes, in the S_i vocabulary system. In this case, system SMA , using text model systems (STM), S_i vocabulary systems and systems of text description output, implements the extension of the corresponding S_i with new components for which a text description has been deduced.

In the instance of detecting parameters with values not within the acceptable threshold, or which fail to meet the specified requirements, a diagnostic model (MD), solves the task of detecting, localizing and recognizing malfunctions to the extent of its capabilities. This is necessary because in these cases an effective reaction on detected unacceptable deviations is needed. Obviously, in these cases some processes may have to be blocked.

Using logical methods in tasks of heuristics generation

Because diagnostic tasks can be solved on the basis of using heuristics $\mathcal{E}r_i$, and the latter are a system of rules that are used while making decisions in a process of implementing a diagnostic algorithm, or for its preparation, it is reasonable to use methods of mathematical logic to generate them (Slupiecki, Halkowska & Pirog-Rzepecka, 1999).

Mathematical logic, in this case, is used to describe methods for implementing links between the system of text models $STM(TM_i, SMA, Sc_i)$, diagnostic models and other models used for the control and maintenance of STO in general. To implement these methods, the following tasks must be considered:

- tasks of transition from text fragments $tm_i \in TM_i$ to logical formulae describing tm_i with corresponding adequacy, which would provide effective usage of deduced heuristic rules;
- determining methods for choosing necessary $tm_i \in TM_i$;

- proving consistency or absence of contradictions $L(\mathcal{E}r_i)$ with the system of logical formulae describing the solutions of tasks implemented in $MD(STO)$;
- developing methods for the extension of logical formulae $L(\mathcal{E}r_i)$ interpretation to the interpretation of tasks solved in MD ;
- if the result of MD functioning is obtained data for which there is no corresponding interpretation in MD , then it is necessary to solve the task of output for corresponding interpretative extensions and their transfer to the corresponding TM_i and MD .

Transformation of fragments $tm_i \in TM_i$ to a logical form is based on methods of using semantic parameters σ^i , as stated previously (Korostil, 2013). Considering this, to form $L_i(\mathcal{E}r_i)$, limitations in the interpretation of corresponding variables must be taken into account, and modal logic used. For this reason, logical formulae of deduced heuristics can be consistent within the limited boundaries of the definition of variables. This is implemented due to the use of modal logical operators. One example of logic that includes these operators is non-monotonous logic with defaults (Reiter, 1980). An example of one output rule which is called a default is $(\alpha \& M\beta) \rightarrow \gamma$, which has the following interpretation. If we believe in α and if β is true, then we take for granted that γ takes place, where M is a default operator. In this case, extensions of the output system is used with the corresponding interpretations, listed below.

1. A modal rule of output by observability, or introspection is: $p \rightarrow Lp$, and its interpretation lies in the following: « p has to be correct», provided p is correct.
2. A scheme of knowledge axiom: $Lp \rightarrow p$, which means «something that is known to be true».
3. A scheme of positive introspective axiom is described by the following relation: $Lp \rightarrow LLp$, where operator L means «known». Then, the mentioned scheme asserts that «if I know p , then I know that p is known to me».

Similarly, interpretation for a scheme of negative introspection axiom is introduced. Introspection, within the scope of this paper, is used to interpret limitation conditions for the definition range of the corresponding logical variables (McDermott, 1982).

Using non-monotonous logic allows us to prove that a certain statement is possible or can be deduced on the basis of using the corresponding logic. This logic indirectly allows us to accept the deduced formula as true, and using the corresponding operators L and M , gives a non-monotonous

nature to the corresponding logic. Modal operators do not affect the interpretation of logical functions. According to a classic axiom system, modal axiom schemes and output rules, generating an output of formulae $L(\mathcal{E}r_i)$ does not lead to inconsistencies within the scope of the subject area of interpretation. This means that within the logical approximation, description of $\mathcal{E}r_i$ as $L(\mathcal{E}r_i)$ will not lead to inconsistencies with the logical interpretation of processes implemented in MD .

Let us review the ways of implementing solutions to the above-stated tasks, which occur while using logical formulae in diagnostic tasks. A choice of $tm_i \in TM_i$ is performed on the basis of text descriptions of the diagnostic system $TM_i(MD)$. This description represents processes implemented in MD . Thus, $TM_i(MD)$ contains descriptions of all known parameters which are related to the class of diagnostic parameters.

Within the $TM_i(STO)$, diagnostic parameters are also described, because they represent, on the level of functional parameters, the functioning processes of the corresponding fragments of STO . However, from the point of view of functioning process description $Pr_i(STO)$ they can be redundant. Their description in $TM_i(STO)$, unlike the description in $TM_i(MD)$, besides the identifiers, contains a description of interpretation of their current values. A simple example of $\mathcal{E}r_i$ could be heuristics of threshold analysis type, which is formally described by this relation:

$$\mathcal{E}r_i(p_i^d) = \left\{ \left[p_i^d(\xi_i) < \Delta_i^d \delta(\xi_i) \right] \rightarrow \left[Pr_i(St) \setminus p_i^d(\xi_i) \right] \right\} \quad (4)$$

Let us examine how, based on the semantic analysis of TM_i , implicit functional links between different parameters are detected. Implicit functional links can only exist in instances when the corresponding parameters in TM_i are described in the different sentences, ψ_i and ψ_j . The system of semantic analysis SMA establishes an implicit link between the parameters p_i^d and p_j^d , if in the corresponding $tm_i \in TM_i$ and $tm_j \in TM_i$ the values of these parameters are changed synchronously. Synchronisation in this case means that during two consequent cycles of analysis of TM_i , the corresponding parameters would be changed by the values described by a certain known functional dependency. In most cases, a linear function is chosen as this dependency.

If the generated $\mathcal{E}r_i$ has not led to, for example, the shortening of a monitoring cycle, then SMA system implements an extension $\mathcal{E}r_i$, that lies in continuing

additional analysis of implicit links between p_i^d and p_j^d . This would allow a shortened time of implementation of the cycle of diagnostic process strategy of $St_i(MD)$.

Organising the process of diagnostics of a technical object

Let us examine the process of forming and implementing strategy for STO parameter monitoring. A monitoring strategy $St_i(SMO)$, implemented within the corresponding methods or the model SMO , is defined by the following parameters and characteristics of strategy St_i :

- time interval τ_i , when the monitoring process is implemented;
- number of parameters p_{ij}^d , chosen for control, where i is a monitoring cycle number, j is a corresponding parameter index, written as (λ_i) ;
- way store act, or reaction discipline of St_i on the value of parameter under check (Dr_i);
- controllability measure of the strategy (Mu).

Time interval τ_i is a parameter of St_i and its value can be defined for the current time point, including using the corresponding heuristics $\mathcal{E}r_i(\tau_i)$. Obviously, during the operation of a diagnostic model $MD(STO)$ the value of τ_i can decrease or increase.

Parameters p_{ij}^d , controlled by the monitoring system SMO , can also be chosen on the basis of using certain heuristics $\mathcal{E}r_i(p_{ij}^d)$. This is caused by the fact that the check-up of all p_{ij}^d each time SMO is activated is not reasonable, because certain p_{ij}^d can remain unchanged during the current check-up period. A check-up period in this case is understood as a value $\Delta t_i = \tau_i + t_i$, where t_i is an interval duration between regular check-up cycles. Within the scope of processes $Pr_i(St_i)$, the way of reaction of St_i on changes of certain parameter values is determined. Because the value of t_i can vary, a task appears to determine the conditions of activation for the next monitoring cycle. Solutions for this tasks can be based on using data regarding the current level of system safety, taking heuristics $\mathcal{E}r_i(t_i)$ into consideration as well. A measure that determines the strategy controllability is defined by the following features:

- possibility to change, during implementation of the strategy St_i , the tactics determined when it was prepared, which means that the influence of external factors can change the sequence of parameter monitoring and one or another analysis depth of a certain parameter within the acceptable range;
- monitoring processes can change the trajectory of the search for data sources that characterise the

corresponding events, appearing during the system functioning and caused by external factors.

Using heuristics in diagnostic tasks is based on the analysis of conditions generated on the basis of the following rules:

- heuristics gives a binary result regarding the making of the corresponding decision;
- heuristics can use logical variables that are not present in the diagnostic model but characterise W_i ;
- variable values are determined on the basis of setting up thresholds for parameter values identified by these variables;
- current values of diagnostic parameters, if they have gone from one value range to another one, are written in the vocabularies Sp_i in the data register mode;
- activation of recording the value of the next parameter is performed by each single source of corresponding information, based on their priorities.

An important element of MD is the task of localizing the malfunction. This task is closely related to recognizing the malfunction. In this case, recognizing the malfunction corresponds to detecting the reasons that caused it, which is the final goal of MD . In this case when an unacceptable change of a diagnostic parameter value is directly related to the reason of its deviation from normal values, Zr and Zv are the same. These cases are grouped in a separate malfunction class. In most cases, sensors of diagnostic parameters p_i^d are not directly related to the reasons of occurrence of the corresponding deviations. In a general case, the change of a parameter p_i^d into an unacceptable value range is caused by known reasons, unknown reasons, or a combination of known and unknown reasons.

In all cases, the localization task lies in determining one possible reason for the occurrence of the deviation. For this to occur, additional tools must be used, namely heuristics. Because heuristics are out of range of MD , it becomes possible to extend data regarding possible unknown malfunctions. In general, reasons for malfunction occurrence will be considered for certain events, occurring within the diagnostic object.

If we accept that an event y_i is the diagnostic parameter p_i^d going outside the acceptable range because of some reason, or $p_i^d > \delta(p_i^d)$, the corresponding event is described by a logical formula $L_i(p_i^d)$. This formula, together with the logical formula of the corresponding heuristics $L_i(\mathcal{E}r_i)$, or $L_i^\mathcal{E}$, must ensure the possibility of detecting reasons for

the occurrence of $p_i^d > \delta(p_i^d)$. If a possible reason for the occurrence of $p_i^d > \delta(p_i^d)$ from $[L_i(p_i^d) \& L_i(\mathcal{E}r_i)]$ cannot be determined, it means that from the system $[L_i(p_i^d) \& L_i(TM_i)]$ a new heuristics formula $\mathcal{E}r_i$ has to be deduced, which would ensure the necessary output: $[L_i(p_i^d) \& L_i(TM_i)] \rightarrow L_i(\mathcal{E}r_i)$. Solving this task on a basic level is performed on the basis of implementing the following processes.

1. Modification of TM_i is implemented by the system of modification and analysis SMA using semantic vocabularies S_c , $TM_i \rightarrow TM_i^*$.
2. In the modified TM_i^* a semantic analysis of description for the corresponding STO components is implemented. On the basis of this analysis, indirect links between reasons of malfunction occurrence Ne_i and diagnostic parameters p_i^d are established, described by the relation:

$$\mathcal{F} \{ \sigma_i^d(TM_i^*) \rightarrow \sigma_i^d[j(p_{i1}^d, \dots, p_{ik}^d) * j(p_{e1}^d, \dots, p_{ek}^d)] \}$$

$$\rightarrow \{ \mathcal{E}r_i[P(p_{i1}^d, \dots, p_{ik}^d) * P(p_{e1}^d, \dots, p_{ek}^d)] \} = \{ \mathcal{E}r_i^*(Ne_i) \}$$
 (5)
3. $\{ [L_i(p_{i1}^d, \dots, p_{ik}^d) * \mathcal{E}r_i^*(Ne_i)] \rightarrow L_i^*(\mathcal{E}r_i) \} \rightarrow \mathfrak{S}^R(L_i)$ is generated.
4. From the system $\mathfrak{S}(L_i)$ the formula $L_i^{Ne}(p_{i1}^d, \dots, p_{ik}^d)$ is deduced, from which the reason of Ne_i occurrence is determined.

Conclusions

The approach given in this paper is proposed to be used to organise a diagnostic system based on using text description models for technological processes of STO system functioning, and it is oriented towards use in a system complex enough with regards to its structure, as well as the number of functional processes implemented in such an object. This approach is especially effective for STO which have a big service life, which provides a great number of functioning cycles.

By using text models, it is possible to detect malfunctions which arise, because the data from the text models allows the detection of implicit relations between parameters, if they exist.

Since heuristics are formed not only on the basis of data possessed by the diagnostic model of a technical object, but also on the basis of data of the text model that describes a technical object in general, it becomes possible to extend the conditions which can be used by diagnostic algorithms. This extension ensures the correct decision is made by the diagnostic algorithm, if an ambiguous situation arises during its functioning.

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Engine room fire safety

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Key words: fire safety, engine room, recommendation for fire safety, rules and regulations, factors, prevention

Abstract

The paper characterizes an engine room as a place of a fire's origin and its spread. It presents potential sources of fire and fire protection onboard. Examples of international rules and regulations are described as well. It also gives the statistics and some scenarios for fires and some recommendations for machine spaces. It presents problems of engine room fire safety, understood as a result of the analysis of different criteria. The engine room was chosen for analysis because many factors whose presence result in a fire could be found there in the way of combustible materials: fuel oil, lubrication oil, hydraulic oil and thermal oil consumed by the main engine, generator engine, boiler, thermal oil heater and hydraulic oil equipment, paints, solvents etc. Sources of potential fires are mainly the hot surfaces of exhaust gas pipes, turbochargers, boilers and waste oil incinerators, ignitions, sparks, static electricity etc. In addition, many engine room fires have an electrical source, such as electrical short-circuits and thermal overheating in the switchboards. Approximately 70% of fires in the engine room have typical scenarios: the outflow of combustible liquid and contact with a hot surface and can reach temperatures between 700–1000°C. They spread rapidly, their power and dynamism depending on the intensity of the outflow of the combustible liquid and its properties, but also the local conditions and the geometry of engine room as well.

Fire safety in engine rooms is determined both by good design and the company's and crew's focus on fire prevention. Some of the recommendations are high standards of cleanliness in the engine room, regular checks of materials used for insulating high temperature surfaces, attention to fire risks when repairs and maintenance works are carried out and many other factors.

Introduction

Many factors whose presence could result in a fire origin are found on ships. They are combustible materials, e.g.: fuels, oils, some cargoes, solvents, paints, etc. and sources of potential fires, e.g.: mainly hot surfaces, sparks, static electricity, fire etc. Firefighting conditions are different from those on land. Fires onboard ships are very hazardous and costly.

The fire protection of a ship is accomplished by so-called active and passive methods. First, include fire extinguishing appliances and media use. The passive methods are connected with restricted use of flammable materials, they determine the construction of the ship's bulkheads, separation of spaces with

fire-resisting bulkheads and decks, fire protection of evacuation roads and division into main vertical zones. Furthermore, the crew should be adequately trained and with passengers, should act according to proper procedures in case of fire (Krystosik, 2010).

The engine room is the most hazardous region of the ship. Restricted space, oxygen, many potential ignition sources and a high amount of different flammable materials make this region particularly vulnerable to a fire's origin and its spread (Figure 1).

It is important to remember that the cost of an engine room fire can be about 1–4 million USD for a cargo vessel and much more for a passenger vessel. Engine room fires are also very dangerous for crew members working in that area and firefighters too (DNV, 2000).



Figure 1. Engine room fire (DASPOS, 2016)

Fire statistics

Most accidents happen on roads. Seas and oceans are safer means of transport (U.S. Coast Guard and Canadian Transportation Safety Board, 2011).

Annual Overview of Marine Casualties and Incidents 2014, a report from the European Maritime Safety Agency (EMSA, 2014), shows the number of casualty events by severity. Flooding/Foundering was the event that led to the highest number of very serious casualties between 2011 and 2013 (31%). It is followed by collision (20%) and fire/explosion (13%).

The total number of lives lost was 228 (62 in 2011, 92 in 2012 and 74 in 2013). 1,982 ships reported some damage, the largest category being cargo ships (48%). More than 50% of the occurrences happened in internal waters (archipelago, fairway, channel, river or port area).

Other statistics show that fires and explosions are placed in third or fourth place in statistics (Transportation Safety Board of Canada, 2014).

Statistics prepared by the Det Norske Veritas show that much more than half of fires originate in engine rooms. The most common scenario is flammable oil contacting a hot surface (Figure 2).

More than 50% of all engine room fires (excluding yard repairs) were caused by the combination of oil leakage with a hot surface. Whereas sources for oil leakage are numerous and difficult to reduce, it is relatively easy to identify and remove hot surfaces

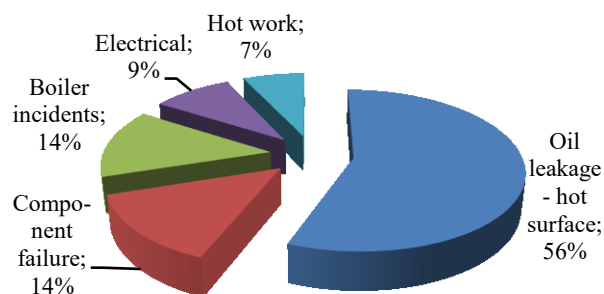


Figure 2. Causes of fire (based on: DNV, 2000)

(DNV, 2000). Fires caused by oil leakage onto hot spots are, in general, more serious than fires caused by other factors (DNV, 2016b).

In 2014, deficiencies in fire safety accounted for 13.43% of all deficiencies recorded (a decrease from 13.57% in 2013). The number of deficiencies in this area decreased from 6,657 in 2013 to 6,176 in 2014 (Port State Control, 2014).

Flammable materials and sources of ignition in engine rooms

An engine room is a place characterized by high a risk of fire occurrence. In particular, there is always danger of fire because of the presence of large volumes of fuel oil, lubrication oil, hydraulic oil and thermal oil consumed by the main engine, generator engine, boiler, thermal oil heater and hydraulic oil equipment, which are flammable materials. Additionally, many potential sources of ignition are present in engine rooms. Hot surfaces of exhaust gas pipes, turbochargers, boilers and waste oil incinerators are some amongst the most dangerous.

Engine room fires are one of the most important issues of fire safety on a ship. They can easily spread and cause serious casualties, such as loss of human life and disabling of the ship due to machinery damage. They can spread to other regions of the ship, such as accommodation spaces etc. Engine room fires often occur when ships are at sea, which can result in serious problems with navigation too. Engine room fires with serious consequences are, however, usually a result of multiple barriers failing in sequence, not of a single failure.

The engine room is a place where some areas should be emphasized as special cases, generating high potential risk. They are as follows: FO injection pipes, FO service pipes and FO valve-cooling oil pipes attached to the diesel engine, LO service pipes and hydraulic oil pipes attached to the diesel engine, flammable oil pipes, flammable oil pump and strainer, FO heater, LO heater and cooler, FO purifier, LO Purifier, FO burning unit for boiler, thermal oil heater, inert gas generator, incinerator, level gauge, fittings and oil tray of flammable oil tank, sounding pipe-head of double bottom FO tank, special pipe joint (threaded pipe joint, compression fitting joint etc.) and expansion joint in the flammable oil piping (NKK, 1994).

Flammable materials are: fuel oil, lubrication oil, hydraulic oil, thermal oil, waste oil and fuel additive. Most of fires occur due to the leakage and spray of flammable oil.

Examples of ignition sources are as follows: exhaust gas pipe, steam pipe, turbocharger, electrical equipment, boiler, thermal oil heater and incinerator, welding spatter, cigarettes, etc. (NKK, 1994).

Figure 3 presents the possible sources of fire in engine rooms in different conditions of exploitation. Most fires occur at sea. Places like a turbocharger, switchboard, generator engine, were highlighted as most dangerous. The fires did not occur uniformly at all locations in the engine room space. It is observed from the figure that the fires were concentrated at certain high-risk areas. Fires in the engine room were concentrated in areas where flammable oils are liable to leak easily, and in the vicinity of an ignition source such as a high-temperature surface or where there is electric equipment liable to generate sparks or overheating. Fuel oil pipes fitted to main engines, or generator engines, burner fuel injection pipes in boilers, exhaust gas pipes, turbochargers, and main switchboards are locations with a high fire

risk. Countermeasures for preventing fires must be adopted as a top priority at these high fire-risk areas.

As shown in Figure 3, the lower floor level is the area with the minimum risk of fire when the ship is at sea. Fire could occur at the lower floor level, e.g. due to spraying of oil from a short sounding pipe during oil replenishing work when the ship is anchored, or due to sparks generated during welding or gas-cutting work at the time of repairs in a shipyard. This area may be considered prone to fires because of human errors during maintenance.

The most frequent causes of damages to fuel systems' elements which result in leakages are vibrations of the machine and other systems elements. The cracking of pipelines resulting in fuel leakages is possible. The pressure in a fuel system may also cause flammable hydraulic mist in the air (Charchalis & Czyż, 2011). Hot gases or flames extracted from the engine room could heat the bulkheads to the temperature at which fire spreads through the

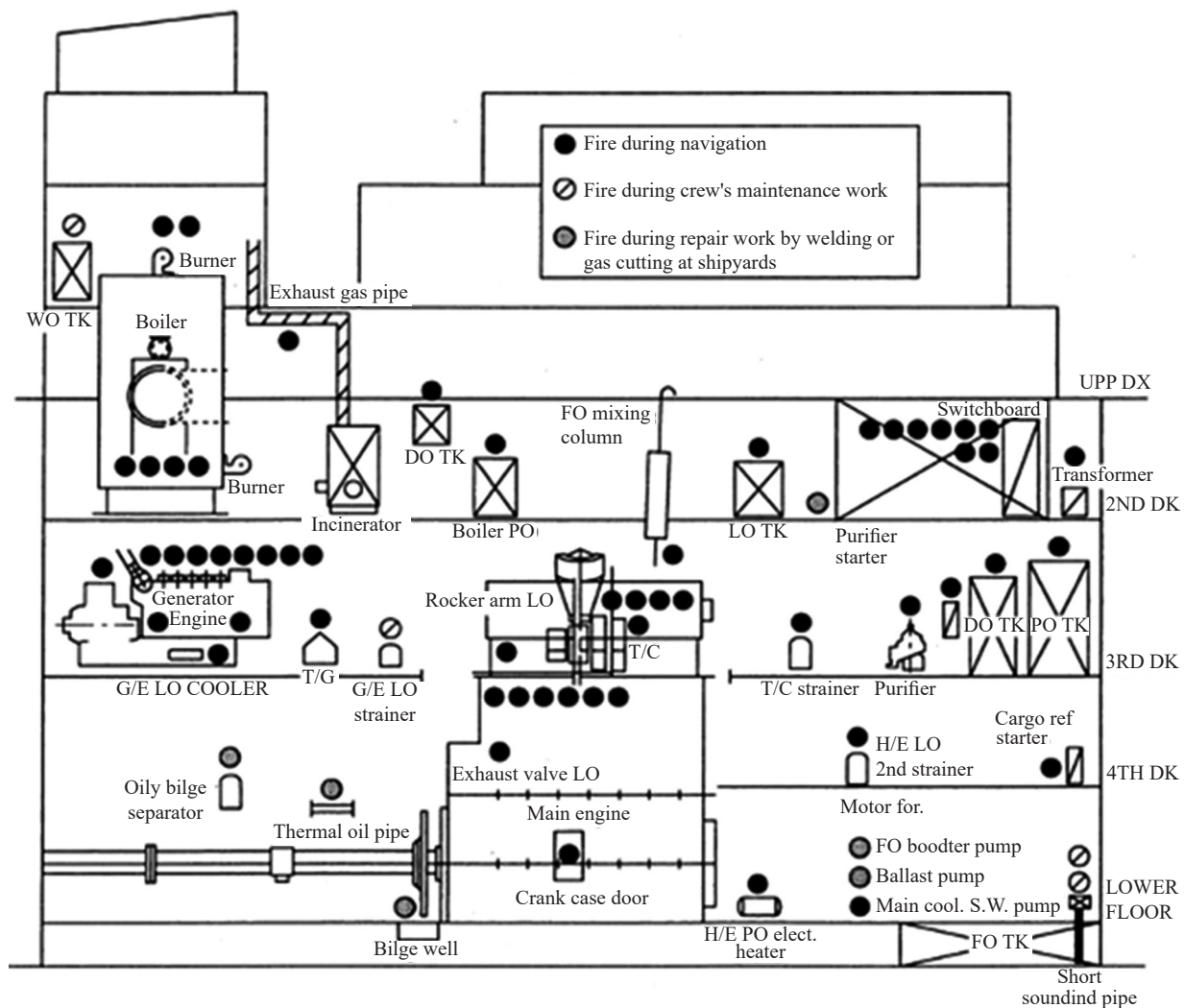


Figure 3. The sources of fire in engine room (NKK, 1994)

bulkheads, especially when they are insufficiently insulated or the insulation is not tight enough. More than 60 percent of ship fires have similar scenarios: their source is in the engine room, they spread over the engine room and through the casing to the superstructure where accommodation spaces are located. The ways that fire spreads are cables lines, ventilation ducts, shafts, bulkheads, open doors and pipes with unsuitable insulation.

An engine room fire has a typically sharp nature. It progresses rapidly to full development (without initial phase). The dynamism of a fire depends on intensity of the outflowing combustible liquid, its properties, local conditions, geometry etc. The fire's power is, in the early stage, roughly equal to the quantity of heat produced per unit of time by burning the leaking fuel. Subsequently, the power of the fire increases due to combustion of other combustible materials in the room, including, primarily, the insulation of electric cables. In terms of quantity and intensity of the heat release in machinery spaces, cable insulations are second in the order of the source of risk. Fires in machinery spaces are much more intense and dynamic, especially in the initial phase, compared to fires in accommodation spaces (Getka, 2011).

Fire protection methods

Recognition of the importance of fire prevention issues forth from the many papers and documents dealing with the problem. Although fire safety has always been a primary concern, little progress was made to make ships safer until the disaster of the Titanic. Nowadays, most regulations pertaining to the fire safety are derived from the International Convention for Safety of Life at Sea, 1974 (IMO, 2015). There are basic principles listed in SOLAS, which form the basic philosophy of fire protection.

Thus, fire safety encompasses the obligation to prevent fire from originating or to immediately stop it. Active methods of fire protection describe fire extinguishing appliances and means (used by crew). Passive methods describe the construction of the ship itself (the restricted use of combustible materials, separation of spaces by fire-resistant bulkheads, decks or air gaps, fire protection of evacuation roads and division into main vertical zones). A balance between the four methods of fire protection (active, passive, human factor elimination, safety management) should ensure the highest safety level.

The philosophy of fire protection is to prevent the occurrence of fire and explosion; reduce the risk to

life caused by fire; reduce the risk of damage caused by fire to the vessel, its cargo and the environment; contain, control and suppress fire and explosion in the compartment of origin and to provide adequate and readily accessible means of escape for crew.

Structural (passive) fire protection methods gives some recommendations. They say that the vessel should be subdivided by thermal and structural boundaries; thermal insulation of boundaries should have due regard to the fire risk of the space and adjacent spaces; the fire integrity of the divisions should be maintained at openings and penetrations (IMO, 2015).

For example, machine space should be separated by A-class division. The rules give the type of A-class (A-60, A-0), e.g. machinery space category A by A-60, with service spaces of high fire risk, ro-ro spaces or vehicle spaces, accommodation spaces, control stations, corridors and staircases etc.

Increased attention should also be paid to insulation's surface in spaces where penetration of oil products is possible. The arrangements for storage, distribution and utilization of the oil fuel should be such as to ensure the safety of the vessel and persons on board.

Oil fuel lines should be located as far as possible from hot surfaces, electrical installations or other potential sources of ignition. They should be properly screened or protected to eliminate oil spray or oil leakage contacting hot surfaces. The numerous joints should be properly insulated etc.

Active methods of fire protection in engine rooms are connected with fire extinguishing, fire detection and fire-alarm systems. Approved methods should be installed in all Category 'A' machinery spaces and cargo pump rooms. The choice of extinguishing medium should be suitable for defined areas. The most commonly used in the machinery spaces of cargo vessels are foam, carbon dioxide gas, dry powder or other approved mediums suitable for extinguishing oil fires. The firefighting equipment should be in accordance with the minimum recommendations (IMO, 2015).

The simplest emergency procedure imaginable for crew in case of fire onboard, is the word fire itself. The acronym FIRE is the instruction for what to do. F – stands for find the fire; locate its source. I – stands for inspect, isolate and extinguish, then R – for report, raise the alarm, inform crew, and finally E – for Extinguish. The crew should remember not to put itself in danger (Hope, 2016).

To minimize the consequences of fire spread, crew members are regularly trained to act properly in

case of a fire and its spread. They are obliged to take part in courses organized by land training centers and onboard exercises, which are organized to let the crew fix their duties, to understand the proper chain of command, to get to know the ship's architecture better and to try to cope with stress factors. During simulated alarms, each member of the crew has to prove the knowledge of their duties and of how to use the equipment correctly.

To ensure the adequate level of fire safety, engineering analysis of fire risk evaluation should be undertaken. This should include, at the very least, identification of possible fire and explosion hazards; identification of the potential ignition sources; identification of the fire growth potential and fire dynamics; identification of the smoke and toxic effluent generation potential; identification of the possibility of spreading fire, smoke or toxic effluents to other areas (IMO, 2015).

Typical scenarios- examples

Typical scenarios of engine room fire involve hot surfaces and oil leakage. Two examples of typical fire scenarios described by IMO are presented below.

First Scenario

The ship's fire detection system indicated a fire in the engine room (4 hours after the ship departed from port. 2. The second engineer investigated and found that diesel generator No. 3 was on fire, caused by the failure of a flexible fuel hose (long-term rubbing and chafing; the maintenance of the generator's flexible fuel hoses was inadequate and hoses longer than specified by the generator manufacturer had been used). He raised the alarm and discharged a portable extinguisher towards the fire and stopped the engine-room ventilation fans before retreating from the engine room. The crew assembled quickly, operated systems to stop the engine room pumps, fuel tanks, quick-closing valves and prepared to fight the fire. The fire was put out by the engine room Halon fixed fire-extinguishing system (IMO, 2016).

Second Scenario

The No. 4 diesel generator on the 45,000 gt container ship suffered a catastrophic failure, which resulted in disabling the generator and the outbreak of a fire (one or more of the connecting rod palm nuts or counterweight nuts had not been sufficiently tightened – or over-tightened – during recent overhauls

and the resultant failure of one of the retaining studs was the initiator of the catastrophic engine failure). The crew members were evacuated and the fixed carbon dioxide (CO₂) fire-extinguishing system was used. The decision to use the CO₂ system was prudent, and together with the prompt use of the ship's fire dampers, remote valves and emergency stops reduced the severity of the damage to the generator room (IMO, 2016).

Some recommendations for engine room fire safety

Engine room fire safety comes as a result of good design, company, crew, authorities and classification societies work (Gard, 2016). The classification societies pay attention to measures onboard. The diagram below (Figure 4) shows some of the recommendations, the elements of so-called safety culture onboard.

The most dangerous possibilities in engine rooms from point of view of ignition are hot surfaces. Most fuel oils may spontaneously ignite if they hit surfaces with temperatures above 250°C. Class rules require that all surfaces above 220°C are shielded or insulated. As commonly noted by surveyors, such protection is often impaired under operation.

The Det Norske Veritas recommends the examination of the following potential hot surfaces: engine "body", indicator valves, cylinder hoods, exhaust pipe from each cylinder, tie-in to exhaust manifold, exhaust manifold, particularly overlaps between steel sheets and laggings, foundation and lifting lugs on exhaust ducts, turbochargers, particularly connecting flanges, cut-outs for pressure/temperature sensors, etc. (DNV, 2016a).

Recommended for checking in case of potential fuel leakage sources are flexible hoses, couplings, clogged filters and fractured pipes. Attention should be paid to installation, location and condition of all these components. It is recommended that the oil systems in engine rooms on ships in operation are also inspected periodically by the owner, as an addition to class inspections (DNV, 2016a).

As aforementioned, most engine room fires occur as a result of oil leakage contacting hot surfaces. To minimize this possibility of fire origin, updated design for integrated insulation box and turbocharger end insulation could be implemented. The integrated insulation box and turbocharger end insulation is an optimized mating with the retrofit design of insulation box and Wärtsilä Bellow and connection insulation. The aim of the retrofit design is to fulfill all

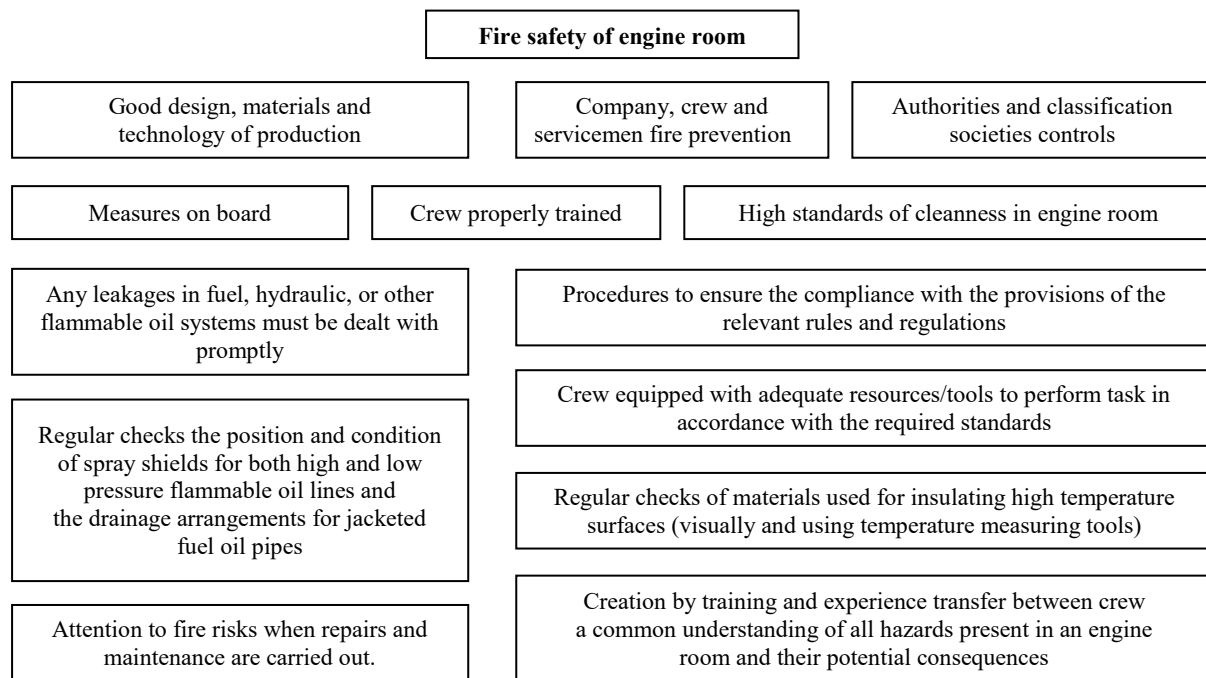


Figure 4. Fire safety in the engine room – some recommendations (based on: Gard, 2016)

actual requirements in terms of hotspot propagation and fire prevention. The updated design is available for Wärtsilä 46 both inline and V-engines (Wärtsilä, 2016).

Conclusions

The engine room is a place characterized by high risk of fire occurrence and spread. Restricted space, oxygen, many potential ignition sources and high amounts of different flammable materials make this region very particularly vulnerable to a fire's commencement and its spread. Engine room fire rapidly becomes fully developed. Many different factors whose presence could result in a fire are present onboard and it's impossible to eliminate them. Good design, arrangement, responsibility and experience are the key to protecting an engine room from fire during its use. Passive and active methods of fire protection are used to eliminate the potential for fire and its spread. They are connected with the construction itself and with the use of fire extinguishing systems and portable means. Machine space is separated by A-class division, hot surfaces are insulated etc.

Attention should be paid to measures onboard, to examine so-called checkpoints in the engine room regularly and with care. The simplest recommendation is cleanness of engine room. There are modern integrated insulation boxes to eliminate potential fire sources and many other ideas to improve fire safety.

We must be aware that it is very unlikely that we will ever completely succeed in the full elimination of fire occurrence in engine rooms from either technical or man-made causes. Nevertheless we are bound to search for optimal technical solutions, which would at least minimize such risk.

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Ship fires caused by primary failure of the fuel filter of the engine driving the generator

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Key words: merchant vessels, functional systems, adverse events, reciprocating internal combustion engines, investigations, accidents

Abstract

This article presents selected results of investigations on adverse events of ships throughout one year. The investigations included mainly merchant vessels used to transport bulk material and heavy objects. Ships have been divided into functional systems and elements and into navigational and machine parts. An attempt was made to classify the causes of accidents and evaluate material losses. The quantitative analysis of the causes of the events leads to different conclusions than those reached on the basis of the analyses of losses. Although the failures on-board the vessel occurred more frequently, the costs of machine adverse events were larger. The most critical consequences was fire of a ship caused by loosening of the bleed screw of the fuel filter. Auxiliary engines of the vessel were operated in different external and internal conditions, and were fed by distillation fuel. As a consequence, the evacuation of the crew and fire suppression were required, using the CO₂ installation of the ship. The ship was stopped and deprived of its primary sources of electric energy. An analysis of the event was along with the elaboration of a plan of preventive measures. The results should be useful for selecting the monitored diagnostic objects of vessels.

Introduction

The number of adverse events at sea is still high, although it maintains a long-term downward trend and ships can be considered to be increasingly safe (Brandowski, 2003; Szopa, 2009; Gerigk, 2010; Adamkiewicz, 2014). Despite the use of sophisticated diagnostic systems, adverse events concerning ships and their equipment are still verified, involving the crew and surrounding environment. An operator (navigator or engineer) is still taking the final decision and bears responsibility for the consequences. Sea ships are ranked among technical complex objects, for which control operations use indicators of reliability and safety (Gerigk, 2010). The safety of ships depends on the qualification of personnel and reliability of systems.

Risk is the possibility of the emergence of losses of goods as the result of incorrect functioning of a fragment of the overall system formed by man,

technology and the environment at a specified time (Rosochacki & Pijanowski, 2012). The working environment can, in some cases, represent a threat for man.

In investigations of the safety of machinery, a risk analysis is significant. Determining the accurate level of technical risk is understood to be an important factor in economic enterprises and the inherent technical activities (PN-EN ISO 12100, 2011). Maritime safety includes the state of sea conditions, where the risk to health, property and the environment does not exceed the acceptable level of risk (Kopacz, Morgaś & Urbański, 2006).

Hazards are classified in terms of their origin or from the point of view of the nature of the potential damage. The following types of sea adverse events were singled out (PRS, 2002; Kopacz, Morgaś & Urbański, 2006): collisions, contact, fire, explosion, loss of integrity of the hull, sinking, input on stranding, no operation of the object, accidents involving

power plant equipment, cargo-related accidents, accidents with dangerous substances, accidents with people.

The hazard is the possibility of the loss of protected goods, which arises due to the occurrence of single adverse event in the system man – engineering – environment or chain of successive interrelated events (Rosochacki & Pijanowski, 2012). The result of accidental events can include: deaths, injuries, loss of the ship or its failure, loss of or failure of other property, damage to the environment. The significance of the damage is determined according to the criteria of safety, performance of a task, and expenses required to repair a failure (financial, labour costs, materials) (Szopa, 2009).

Man, technique and the environment are interrelated, and their state depends on the quality of their interactions (Woropay & Bojar, 2007). External influences at sea include storms, impact of waves, ice sheets, hidden underwater objects, and other ships. With regards to technical objects, sources of risk are, for example, dangerous substances, potential sources of ignition, and electrical discharges.

One of the criteria of quality ship construction is reliability (Tarełko, 2011). Reliability is one of the characteristics of ships and one of the factors ensuring the proper functioning of the ship, guaranteeing the safety of people, cargo, and floating object and the accomplishment of tasks (Girtler, Kuzmider & Plewiński, 2003; Tarełko, 2011).

In the operation of ships it is possible to incur in situations that are normal, complicated, dangerous, emergencies or catastrophic (Girtler, Kuzmider & Plewiński, 2003). Catastrophic failure is a sudden damage causing the total inability of the object to perform all the required functions. The occurrence of different situations during the operation of the vessel depends on the condition of the crew and technical environment. The following factors affect the correct operating of the ship and the safety of the navigation (Perkis & Inözü, 1990; PRS, 2002; Girtler, Kuzmider & Plewiński, 2003):

- correct navigation – maintaining the recommended route of navigation, adapting speed and vessel course to weather conditions and routes (narrow waters, intensive motion, etc.), ensuring the stability and buoyancy of the vessel;
- reliability of equipment and systems – particularly the main, auxiliary, and emergency drives of the ship;
- safety of the cargo – keeping conditions in accordance with shipping requirements.

Exemplary methods of the safety investigations of floating objects

In the analysis of adverse events affecting complex technical objects, such as sea ships, it is necessary to conduct qualitative analyses using the methods of assessment of risk, threat and operational capabilities, kinds and effects of failures, along with quantitative analyses of the methods, e.g., probabilistic, human reliability, tree of mistakes, tree of event.

The International Maritime Organization (IMO) has developed and published uniform rules of conduct for Formal Safety Assessment (FSA) and committed all the sea states that are members of the IMO to apply these principles (PRS, 2002; Girtler, Kuzmider & Plewiński, 2003; Kopacz, Morgaś & Urbański, 2006; Kontovas & Psaraftis, 2009). An example of such a document developed for the safety of bulk carriers IMO is MSC74/5/x, which concerns the integrity of the hull of bulk carriers (PRS, 2002).

The FSA constitutes a methodology whose aim is to enhance maritime security, including protection of life, health, property and the marine environment through the application of uniform rules, analysis and risk assessment, and the assessment of costs and benefits associated with lowering risks to the accepted level. This is achieved by developing a risk matrix, describing the individual levels of risk (Radkowski, 2006).

Safety investigation methods make use of artificial neural networks, and Taguchi and multi-criteria approach to decision-making (Gerigk, 2010). For the estimation of risk, the following criteria can be adopted (Gerigk, 2010):

- matrix of risk acceptance;
- the “as low as reasonably practicable” (ALARP) concept;
- F-C (frequency – consequence) curve concept.

The probability of non-survival as a consequence of vessel collision can be determined by one of four methods (Gerigk, 2010): zero-one, statistic methods based on the definition of the probability of complete survival of the vessel to collision, methods based on the assessment of the behaviour of the ship in the damaged state and identification of the characteristics of a stochastic process of lateral oscillations of the ship in damaged state, methods based on the use of fuzzy set theory. Controlling the level of risk is necessary to design, monitor and influence their significance. The level of risk may be (PRS, 2002): acceptable, moderate or not acceptable.

Many works indicate that the marine power plant is a dangerous space within the machine room of the ship; therefore, to increase the safety of the operator, the International Maritime Organization has developed relevant documents (Monieta, 2013; 2015; Adamkiewicz, 2014). Requirements for control systems of main drives are determined by regulations of classification societies. Reliability machinery and marine equipment are varied according to destination, manufacturer, operating conditions and state of operators.

It is then necessary to estimate and analyse the reliability or unreliability of object in the power plant including, for example, the probability $P_i(\tau)$ of the specific event in time τ . For a direct estimate of the probability, $P_i(\tau)$, as well as of other tress of events, experimental investigations and analysis methods are applied.

Selected measures of safety

The science of safety is developing the aspect of principles and measures of the safety. The measure used to assess the safety is the risk of losses of objects. In order to carry out a risk assessment, one should adopt specific safety criteria, which may be qualitative or quantitative (PRS, 2002).

Risk (R) is a numerical quantity given by the product of the frequency of occurrence of an accident at sea (C) and the severity of its effect (S):

$$R = C \cdot S \quad (1)$$

The frequency of marine accidents (C) is understood as the number of marine accidents occurring per unit of time, e.g. in the year (Kopacz, Morgaś & Urbański, 2006). The risk of an accident is defined as the product of the probability of the risks, P_i , and consequences of the accident, K_i (Gerigk, 2010):

$$R_w = P_i \cdot K_i \quad (2)$$

In risk analyses concerning complex technical objects such as sea ships, different methods are being used for quality evaluations: the risks, threats and operational capabilities, types and effects of failures are determined on the basis of sample holistic models of technical risk for collisions (Vanem & Skjong, 2006; Gerigk, 2010).

The primary measure of safety is the size of the losses due to the occurrence of adverse events. For the test set of ships, the measure of the loss in the period of time $(\tau, \tau + \Delta\tau)$ are collective losses, referring to the group of vessels that can be presented in

relative terms, and expressed as part of a unity or in percentages (Szopa, 2009; Monieta, 2015):

$$S_{zi} = \frac{S_i}{S(\tau, \tau + \Delta\tau)} \quad (3)$$

where: S_i are collective loss, due to the occurrence of the i -th adverse event in the period $(\tau, \tau + \Delta\tau)$, and

$$S(\tau, \tau + \Delta\tau) = \sum_{i=1}^{n(\tau, \tau + \Delta\tau)} S_i, \quad n = 1, 2, \dots, \infty,$$

is the number of adverse events in this period.

Risks can be controlled by taking actions for their mitigation using an active (impact on the cause) or passive (protection against possible losses) approach. These measures should apply to the entire anthropotechnic system: man – technical object – environment.

The indicator of the relative significance of the factor-criterion, K_{ri} over K_{rj} , is expressed as the number a_{ij} (Downarowicz et al., 2000):

$$a_{ij} = \frac{e_i}{e_j} \quad \text{for } i, j = 1, 2, \dots, n \quad (4)$$

where: e_i is the rank absolute criterion K_{ri} matrix; e_j is ruthless rank of the K_{rj} matrix, where $a_{ij} \in (1, 2, 3, \dots, n)$.

The equation of safety, defining the minimum probability of failure, can be written as (Radkowski, 2006):

$$Z = O_{bz} - O_b \quad (5)$$

where: O_{bz} is the load capacity, for example durability; O_b is the load, for example stresses.

In a previous article (Adamkiewicz, 2014) the complexity of maintaining elements of the energy system of the ship was presented in terms of ensuring the safety of its operation and inadequate use of this risk analysis. The previously used strategies for maintaining the elements of power systems of ships in the risk analysis did not constitute supporting information in decision making. They are selected and considered as essential safety measures.

Objects and methodology of investigations

The objects of investigations were merchant ships of one selected ship owner throughout one year. The selected ships navigated in rivers, lakes, seas and oceans around the world. Determined threats were associated with the area of swimming. The ships were divided hierarchically, where functional systems and sub-assemblies were singled out (Monieta, 2013). In this period, 108 adverse events

were registered. Observations of the adverse events and their consequences on the operation of ships have been made. Adverse events have been recorded by the ship owner's insurance and some were also considered by the marine chamber. Accidents involving the crews were also investigated, as described in a previous work (Monieta, 2006). The computer program Amos was used on ships a computer programs Amos were applied for the archiving of data.

Ships were divided in deck, machine parts, and functional systems (Monieta, 2013). Determined systems were assigned to the machine and deck crew. Disruptions in the production process of the ship include changing parameters of movement or detention of the ship, extension of time in port, stop in shipyard, or temporary withdrawal from operation. External conditions such as air humidity, air temperature, air pressure, pollution, biotic hazards (in terms of plant, animal and bacterial microflora), swimming conditions, horizontal visibility, terrain swimming, sea state, direction of the wind, immersion and state of covering of the body, varied considerably.

The ship, on which the catastrophic adverse event occurred, was of type B 542. It was the handy-size ship type with a capacity of 33,780 t, dead-weight built in the national shipyard in 1986. The vessel was driven by a slow-speed engine and three engines driving the generator 6AL20/24 type with the parameters listed in Table 1.

Table 1. Specifications of the 6AL20 engine

No.	Engine type	AL 20
1	The type of structure	In-line engine
2	Bore	200 mm
3	Piston stroke	240 mm
4	Stroke volume	0.007540 m ³
5	Compression ratio	1:12.7
6	Rated engine speed	750 min ⁻¹
7	Rated power	70 kW/cyl.
8	Brake mean effective pressure	1.5 MPa

The up state of the object is the state in which it can carry out tasks in accordance with the requirements under the specific impact of the environment (Girtler, Kuszmidler & Plewiński, 2003; Tarełko, 2011). Systems and assembly ships are assigned to use or operate the machine and crew members on board, in individual stations. The tasks were carried out by the ship's crew in accordance with the certificate of safe manning.

Selected results of investigations

The analysis of adverse events of the merchant vessels were used in selected measures of safety (risk) and economic (the size of losses and harms) consequences of adverse events (Kontovas & Psaraftis, 2009; Rosochacki & Pijanowski, 2012; Monieta, 2013; 2015), including the number of failures, the off-time of operational use, repair time and cost of repair.

The analyses include an estimate of the consequences of accidents to property and the environment. The collective losses due to adverse events, S_{zi} , defined by formula (4), were three times larger in the deck than in the marine propulsion plant (Kontovas & Psaraftis, 2009; Monieta, 2015). This does not mean, however, that the focus should be only on deck objects. Figure 1 shows the maximum collective losses due to individual events occurring in one year. The difficulty in estimating the losses was related to quoting the costs of the events estimated in various currencies. Therefore, calculations were carried out in a common currency, taking into account the dynamics of exchange rates.

Figure 1 shows that a few initiating events (primal events in the sequence of events leading to the accident) led to large collective losses. The greatest loss, and the third in temporary order, was caused by the fires. The second largest collective loss arose as the result of the collision. The losses were calculated with different currencies, depending on the location of the incident and repair. At that time, the PLN was also changed significantly. The event causing the largest losses in the main drive was not considered until the end, while the third event was the most dangerous and required the evacuation of the crew.

The third event was described in terms of collective losses. The fire was the result of the loosening of a vent cork of the fuel filter of the internal-combustion engine driving the generator. As a result of

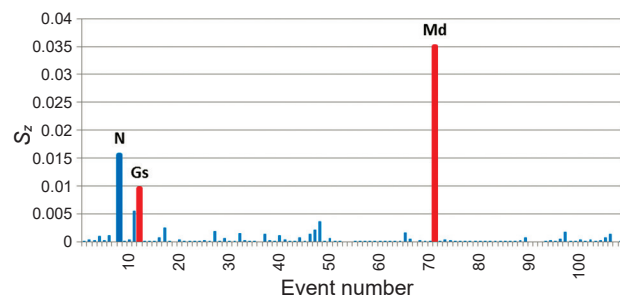


Figure 1. Collective losses of individual adverse events, where adverse event were initiated in the system: N – navigation, Gs – generating station, Md – main drive

the fire, the crew was evacuated and fire suppression was required from the CO₂ installation of the ship. In view of the catastrophic nature of the event, it was analysed in the present study. The view of the auxiliary engine from the side of the filter of fuel is showing Figure 2.



Figure 2. View of an auxiliary engine from side of the fuel filter on the ship from the series B-542: 1 – fuel filter, 2 – filter cover, 3 – turbocharger

The event happened around 22:00. After the alarm system set off, the fire was found in the auxiliary engines room. There was a strong spread of fire in the generating sets compartment and upwards, following the ventilation system. This was the reason for which the crew decided to discharge CO₂ gas into the engine room. As a consequence of the fire and the resulting destructions, the ship was immobilized and deprived of the main sources of electricity.

After towing the ship to the port, the local shipyard conducted the service after the fire under the supervision of the classification society. The cause of the fire, according to the decision of maritime chamber, was flow of the fuel from the filter of auxiliary engine No. 1 to the turbine of the turbocharger. Costs of the event were refunded by the institution with which the ship was insured.

Conclusions

This article established the identification of sources causing threats to the security of the transport system of a ship owner as the result of failures of technical objects. The greatest losses have been caused by fires of components of the marine propulsion plants. Fires and failures of the propulsion system of ships lead to major losses, so they should be kept to the minimum. The examples of adverse events were

described, with a particular focus on essential losses and influence on the safety of the crew and the environment. Initiated fires were detected too late, not extinguished in the bud and led to large losses.

Based on the results of the evaluations, neither the quantitative nor the economic analyses were satisfactory. Some of the frequently occurring adverse events bring small losses, and the outcome of the economic analysis depends on market situations and exchange rates. It is therefore necessary to seek measures that account for the threat and risk. Managing the safety of floating objects is based among other things on risk assessment and on risk management. Set rates of the risk of sea ships should be of help for developing the strategy of the operation and the method of keeping the technical state. Application of scientific research immediately after the adverse events, especially of the diagnostic genesis, should bring useful information.

Credible diagnosis should be used to monitor teams that faced large losses, especially as a result of fire hazards. The improvement in the state of anti-collisions systems is also recommended, because of the large frequency of collisions in the navigation.

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Numerical analysis of the hydrodynamic characteristics of the accelerating and decelerating ducted propeller

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Key words: accelerating and decelerating ducted propeller, pressure coefficient, hydrodynamics characteristics

Abstract

This paper investigates the open-water characteristics of the 5-blade propeller with accelerating and decelerating ducts using the Reynolds-Averaged Navier-Stokes (RANS) equation code. In the first step, numerical open-water hydrodynamic characteristics of the propeller in the absence of a duct were validated using the available experimental data. The shear stress transport (SST) turbulence model was chosen, which shows less error in thrust and torque coefficients than others. In the second step, two accelerating and decelerating ducts, namely ducts 19A and N32, were modeled. In these simulations, the clearance value was selected at 3 percent of the propeller's diameter and uniform-flow conditions were assumed.

After analysis of the mesh sensitivity for the propeller thrust, the results were compared to the corresponding open-water condition values. In this regard, results of the hydrodynamic coefficients, pressure distribution, and coefficients on the propeller-blade surface and ducts were also analyzed and discussed.

Introduction

Since 1930, ducted propellers have been used on tugs, push-boats, trawlers, and torpedoes since. They have also been used in large vessels like tankers and bulk carriers in order to improve the hydrodynamic characteristics in heavy conditions. In an accelerating duct, the flow velocity is increased due to characteristics of the duct and the amount of duct drag force is lower than the lift force, especially in heavy conditions.

The use of an accelerating type of duct, in combination with the propeller, can lead to lower propeller damage and is a better way of increasing propulsive efficiency by axial-losses reduction in a bollard condition. Decelerating ducts decrease the propulsive efficiency but they postpone cavitation inception and the risk of vibration decreases. Therefore, the appropriate condition for military purposes in marine structures is provided. For accelerating

ducts, in general, the ratio of thrust generated by the duct to that of the total propulsor varies by advance coefficients. Also, it may decrease with respect to the open-flow propeller thrust in the same condition for a higher advanced coefficient. Moreover, the propulsor torque generated by the propeller remains constant in both circumstances and is provided only by the propeller. Figure 1 shows the generated lift, thrust, and circulation around decelerating and accelerating ducts.

The history of ducted-propeller analysis goes back to experimental results performed by Stipa (Stipa, 1931) and by Kort (Kort, 1934). In fact, these researchers showed the efficiency increases in accelerating-ducted propellers for heavy conditions. Later, Sparenberg (Sparenberg, 1969) demonstrated that the presence of a duct of finite length around the actuator disc, regardless of its type, in axisymmetric flow has an influence of the second order by accelerating and decelerating the flow, depending on duct

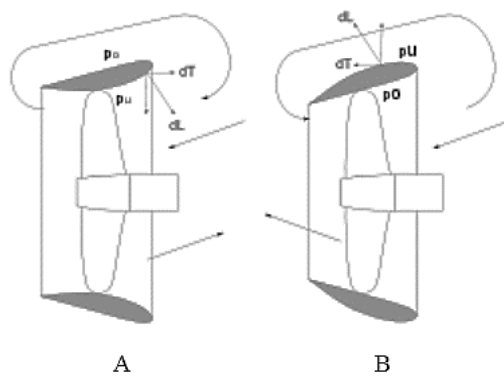


Figure 1. An acceleration duct (A) and a deceleration duct (B)

section profiles. Furthermore, it was also shown that these effects mainly depend on advanced-coefficient ratio and advance velocity, while in the case of light loading, the main efficiency comes from the disk.

In recent years, RANS equations have been widely used by several research groups. For instance, Sanchez-Caja et al. (Sanchez-Caja, Rautaheimo & Siikonen, 2000) used a RANS equation solver to simulate incompressible viscous flow around a propeller in the presence of a duct. In addition, Abdel-Maksoud & Heinke (Abdel-Maksoud & Heinke, 2003) have also investigated scale effects on ducted propellers numerically. Krasilnikov et al. (Krasilnikov et al., 2007), as another example, developed new mesh-generation techniques to study scale effects on the ducted propellers by a commercial RANS equation solver in the numerical analysis. On the other hand, recently, Arazgaldi et al. (Arazgaldi, Hajilouy & Farhanieh, 2009) presented a numerical investigation of solving the RANS equation and used a cavitation model to determine characteristics of two non-cavitating, four- and three-bladed propellers. In this study, the cavitation breakdown was calculated using the CFD method and the obtained numerical results were compared with the experimental ones adopted by the K23 cavitation tunnel at the Sharif University of Technology. The comparison study showed a fairly good agreement. Moreover, Salvatore et al. (Salvatore, Greco & Calcagni, 2011) developed a BEM code entitled INSEAN-PFC to determine inviscid flows in an arbitrary motion for a fluid at rest. The propeller's wake-velocity field was captured and cavitation in uniform flow was predicted. Furthermore, Celik et al. (Celik, Dogrul & Arikan, 2011) obtained the optimum accelerating (19A) and decelerating (N32) conventional duct geometry of the four-blade propeller propulsion efficiency using the lifting-surface theory method. Many turbulence models have been studied recently to determine the

best setting of numerical results based on the CFD method. In this regard, Subhas et al. (Subhas et al., 2012) used a standard $K - \epsilon$ turbulence model in the CFD code Fluent 6.3 commercial software to set the hydrodynamic characteristics of a INSEAN E779a model propeller in both cavitating and non-cavitating conditions. In the numerical analysis of propellers, by comparing the BEM method and CFD method, Gaggero et al. (Gaggero et al., 2013) applied the coupled lifting line/panel method and hybrid design approach for the design of decelerating-ducted propellers to study the cavitation characteristics of propellers, comparing with experimental results. Finally, it was suggested that the RANS equation solver performed better in the same condition and that the panel method was only capable of capturing vortex presence. Moreover Muszyński & Strzelczyk (Muszyński & Strzelczyk, 2013) investigated different duct models in combination with the propeller, in order to specify hydrodynamic characteristics of the propeller. In this research, results of some selected geometries are published and a distribution of velocity for one specific, ducted propeller compared with numerical results, based on the finite volume method. Furthermore, the CFD method was used by Baltazar et al. (Baltazar et al., 2013) to compare the numerical open-water characteristics of ducted propellers with panel method results. The equations were discretized using the finite-volume method and finally the panel-method results were in good agreement with CFD-analysis results in the same condition. Koh et al. (Koh et al., 2015) designed a duct section profile for better characteristics of fishing-boat propellers at a highly-advanced coefficient that is more efficient than 19A. Their experimental results showed a maximum 23% increase in the propeller thrust at highly-advanced ratios, unlike the 19A ducted propeller. Neural networks are one of the newest methods to analyze propeller open-water characteristics. In this regard, Valcic & Dejhala (Valcic & Dejhala, 2015) published the open-water characteristics of four-blade Ka-series located in the 19A duct, using this method. In order to design this solver system, a two-layered, feed-forward, neural-network system was trained. Finally, the data of the azimuth thruster was published. In order to determine propeller pressure distribution, He et al. (He et al., 2015) analyzed the hydrodynamic characteristic of the ducted propeller with MBHM & RSM methods. These numerical results were compared with the standard $K - \epsilon$ two-equation model for the two JD7704+Ka4-55 propellers. Finally, it was shown that MBHM & RSM methods are more usable for determination

of ducted-propeller, hydrodynamic characteristics. Moreover, Majdfar, Ghassemi & Forouzan (Majdfar, Ghassemi & Forouzan, 2015) investigated the variations of nozzle 19A duct length and angle on the Kaplan propeller using a RANS equation solver. Also, Majdfar & Ghassemi (Majdfar & Ghassemi, 2016) extended the calculations of the hydrodynamic characteristics of a ducted propeller operating in oblique flow that is under publication.

In the present work, the RANS equation solver is employed to calculate the hydrodynamic characteristics for the B-series, 5-blade propeller with accelerating (19A) and decelerating (N32) ducts. The investigation is based on the SST turbulence model. A review of the computational equations and methodology is presented and the accuracy of the results is discussed. The simulation results of pressure distribution, velocity field, and open-water characteristics are compared for the two different ducts.

Numerical methods and governing equations

In this paper, the conservation form of unsteady Navier-Stokes equations along with momentum equations has been numerically solved to obtain the velocity and pressure fields in global and local forms.

In this regard, first, the conservation of mass principle has been considered, which leads to the following differential equation in terms of the velocity field and the mass density, and is known as the continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \quad (1)$$

where ρ is the density of the fluid while u_i shows the fluid velocity-vector components. Furthermore, the principal of the conservation of linear momentum was also satisfied by solving the following well-known global Navier-Stokes equation:

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_j u_i) = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g_i \quad (2)$$

where p denotes pressure and g is the gravitational acceleration. In fact, as equations (1) and (2) are coupled, these equations should be solved simultaneously and in an iterative manner. The obtained results, then, have been employed as inputs of a post-processing analysis in local conditions. It should be noted that in case of incompressible flow, the density is constant and the propeller flow is considered to be steady. The RANS equations are solved by the finite

volume method while the SST turbulence model was utilized to compute the transport of the turbulent shear stresses. The SST model was selected since it has been widely used by different researchers in the past and its proficiency and reliability in predicting the flow separation has been well demonstrated. Moreover, the multiple rotating reference frame (MRF) method is used in time limitation problems and the complex geometry of domain and boundaries for ducted propellers numerical investigations.

It is well accepted that the hydrodynamic propeller operation can be modeled by the following non-dimensional equations:

$$K_{T_D} = \frac{T_D}{\rho n^2 D^4}, K_{T_p} = \frac{T_p}{\rho n^2 D^4}, K_T = \frac{T_D + T_p}{\rho n^2 D^4} \quad (3)$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \quad (4)$$

$$\eta = \frac{K_T J}{K_Q 2\pi}, J = \frac{V_A}{n D} \quad (5)$$

where K_{TD} denotes the duct thrust coefficient, K_{Tp} shows propeller thrust coefficient, K_T is the total thrust coefficient, K_Q represents Propulsive torque coefficient, J is advanced ratio, η is the propulsive efficiency, n denotes propeller revolution, D is propeller diameter, T_D is the duct thrust and T_p shows the propeller thrust. Consequently, it can be possible to compare results for the open propeller and the ducted propellers.

Propeller and duct-geometry modeling

In this paper, the influence of two types of ducts was investigated on propeller characteristics. In order to specify the most suitable modeling method for finite difference calculations, the open-water properties of 5-blade, expanded-area ratio of 0.7 are obtained by different numerical methods have been compared with the available experimental results. This comparison study showed that the SST turbulence model is the best one. The details of these numerical simulations have been given in next Section of this paper. The two ducts have been selected in a way that cover both types of accelerating (19A) and decelerating (N32) ones, which are the most common conventional duct profile sections.

The contribution of 19A duct thrust on total propulsive characteristics and produced drag, as the speed of advance increases, have been widely investigated. The results are available especially for Kaplan-type propellers. However, very little

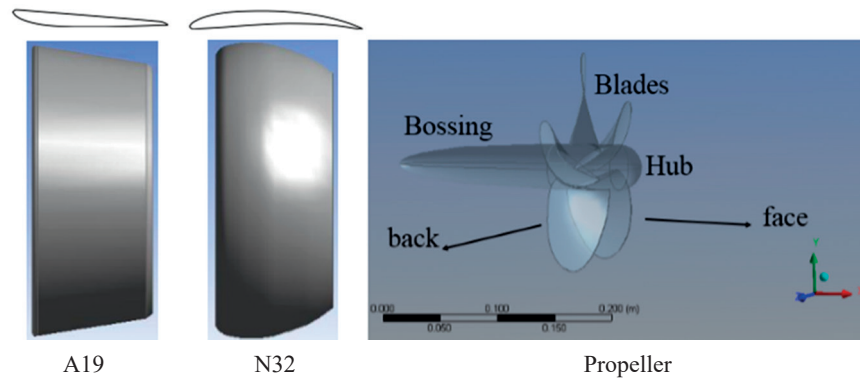


Figure 2. A schematic representation of the propeller and decelerating and accelerating ducts

information is available for propeller characteristics, even in combination with conventional nozzles. Consequently, the results of this research can be of great help in design of the propellers. Moreover, in the current research, the propeller has been investigated and their geometry data are reported in Table 1. The main geometry data of the two ducts are given in Table 2.

Table 1. Main geometry data of the propeller

Parameter	Value
Number of Blades (Z)	5
Expanded Area Ratio (EAR)	0.7
Pitch-Diameter Ratio (P/D)	1.0
Propeller Diameter ($D = 2R$)	0.2 m
Propeller type	B-series

Table 2. Main geometry data of the duct

Parameter	Value
Duct diameter	0.212 m
Duct length	0.106 m
L/D (for duct)	0.5
Clearance between duct and propeller	0.03D
Duct types	19A and N32

Furthermore, Figure 2 depicts the propeller, both ducts (accelerating and decelerating), and the section profiles of the ducts.

Solver settings and validation study

In the present numerical study, the steady-state RANS equations solved for the blades, hub, bossing, ducts, and domains with 3 different finite-volume methods, namely SST, $K - \varepsilon$, and $K - \omega$ turbulence models. These models were utilized to minimize the errors between rotating and stationary surfaces. The obtained results showed that the best agreement has been obtained for the open propeller employing the

SST model and hence this model was selected for the characteristics analyses of the ducted propellers. In fact, the SST model is the combinational and robust eddy- viscosity turbulence model to compute the transport of the turbulent shear stresses, using $K - \omega$ in the boundary layer of domains and accomplishing $K - \varepsilon$ equations out of layer for shear flow.

The propeller is placed in a cylindrical-flow field containing proper dimensions in the range of the other research's flow-field dimensions. For the propeller, the domain cylinder diameter is $3.5D$, and the vertical axis ($x = 0$) is set to $2.5D$ ahead of inlet plane (upstream) and placed $7.5D$ behind the outlet plane (downstream) shown in Figure 3.



Figure 3. Computational domain

The B-series propellers were designed and tested at the Netherlands Ship Model Basin (NSMB) in Wageningen. The open-water characteristics of 120 propeller models of the B-series were tested at NSMB and analyzed with multiple polynomial regression analysis, Bernitsas et al. (Bernitsas et al., 1981). For the present results validation, B-series propeller (B5-0.7 means $Z = 5$ and $EAR = 0.7$) selected. A comparison of the open-water characteristics of the B-series propeller with three turbulence models is presented in Figure 4. The results show that thrust and torque coefficients using the SST-turbulence model has less error relative the two other models. The mesh-sensitivity analysis for the SST turbulence model is shown in Figure 5. The propeller thrust is considered as the convergence criteria. Table 3 is given the thrust and y^+ at various mesh numbers that converged by about 9 million meshes.

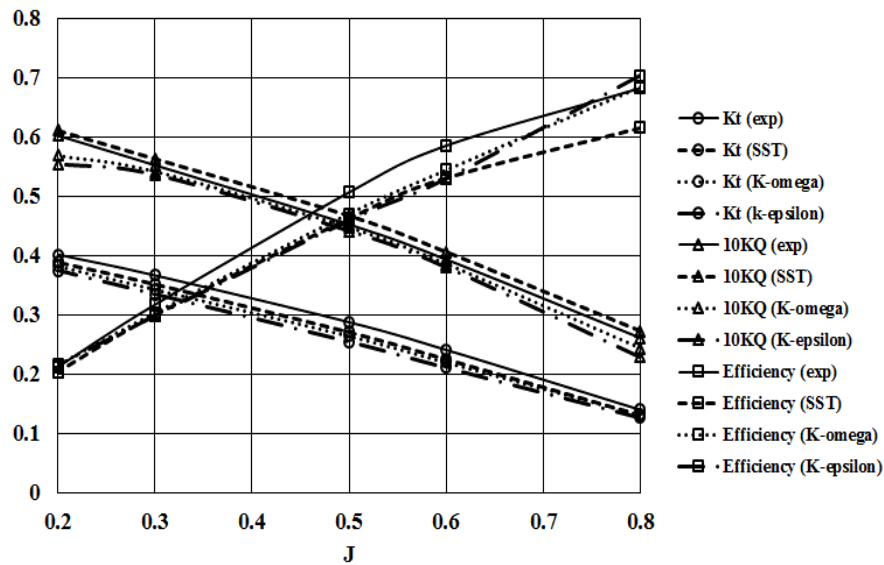


Figure 4. Comparison of the open-water characteristics of the B-series propeller with three turbulence models

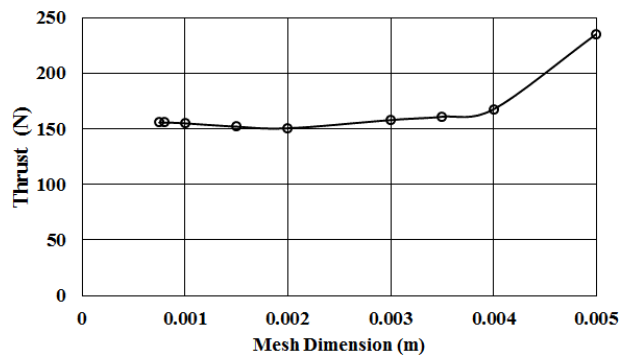


Figure 5. Mesh sensitivity analysis of thrust ($J = 0.3$)

Table 3. Convergence of the thrust by mesh numbers and the value of the y^+

Thrust [N]	y^+	Mesh Numbers
234	2.9	4.3 millions
169	2.4	5.7 millions
162	2.37	6 millions
159	2.26	6.4 millions
150	2	7 millions
156	2.06	7.3 millions
158	2.112	8.7 millions
159	2.111	9 millions
159	2.111	9.1 millions

It should be noted that the reported values of the total mesh numbers in Table 3 have been rounded

to the hundred-thousand. It is important to also note that the mesh dimension for each calculation is the minimum one-side length of the 3D cells that are reported in Figure 5.

It is obvious that the SST turbulence model has higher accuracy compared to the other turbulence models, based on numerical results (Figure 4) for the open-water propeller thrust and torque. The related thrust-coefficients and torque-coefficients errors for different advance ratios are illustrated in Table 4.

In the first step, numerical open-water propeller results without the duct have been validated with experimental results. According to the results, SST has been used that shows a maximum of 7% and 4% errors in thrust coefficient and torque coefficient. This comparison concludes acceptable agreement. According to the published data, an accurate CFD method together with a SST turbulence model is used for the next step of the ducted propeller analysis. The domain geometries for the ducted propeller are similar to the open-water ones.

Ducted propeller results

In this section, the SST turbulence model has been employed in order to compare the characteristics of

Table 4. Comparison of the three turbulence models for open-water parameter errors

J	SST Turbulence model		K-omega Turbulence model		K-epsilon Turbulence model	
	Kt error (%)	KQ error (%)	Kt error (%)	KQ error (%)	Kt error (%)	KQ error (%)
0.8	5.98	4.11	6.51	6.85	9.54	12.33
0.6	6.45	3.05	8.9	2.04	12.46	3.31
0.5	5.78	3.16	8.25	1.18	11.46	2.37
0.3	4.04	1.94	6.5	1.94	8.6	2.91
0.2	3.23	1.4	4.89	5.64	6.62	8.01

the two selected, frequently-used ducts, namely 19A and N32. In this regard, the CFD method, in conjunction with the SST turbulence model, was applied. The finite volume models were discretized by an unstructured mesh in which the cell sizes were small near the blades and ducts (0.8 mm) and increased toward the wall boundary in the cylinder domain, up to 2 cm; it has around nine millions meshes over the entire domains for both 19A and N32 geometries. Figure 6 illustrates the applied mesh pattern for the two models.

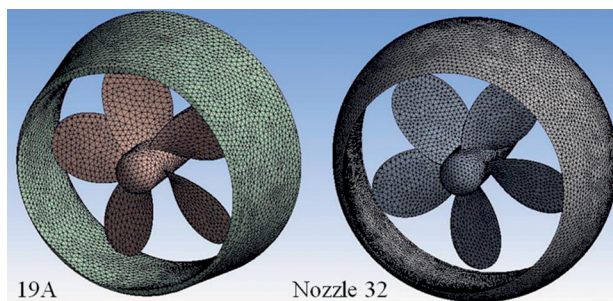


Figure 6. Unstructured mesh cells on ducted propellers

It should also be noted that the dimensionless properties of the numerical studies performed in this section are the same as those given for the open-propeller model in section 4 of this study.

Hydrodynamic characteristics

In this section, the thrust variations with respect to the propeller revolution speed have been explored for the two ducted and open-water 5-blade propeller, assuming a constant velocity of 1 m/s in the inlet plane. The propeller revolution speed was varied between a low RPM of 375 to a high RPM of 1500,

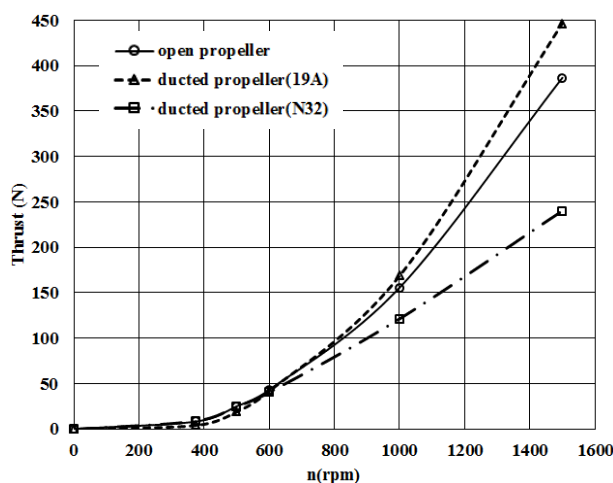


Figure 7. Open-water and ducted propeller thrust comparison

which covers bollard and free-running conditions. There are important differences of total propulsive thrust due to the operation of accelerating and decelerating in different advanced ratios. The total propulsive thrusts for different propellers' revolutions are shown in Figure 7, compared with the open propeller.

Based on Figure 7, it can be seen that the total thrust of the 19A ducted propeller is raised by increasing the rotational speed of the propeller and ascending above the open curve at 600 RPM. In contrast, the total thrust of the N32 ducted propeller started to drop under the open curve at the same condition. It can also be observed that the ducts have no effect of propulsion in this speed of rotation. The effects of the N32 and 19A ducts on the total thrust coefficients are also shown in Figure 8, for the sake of comparison.

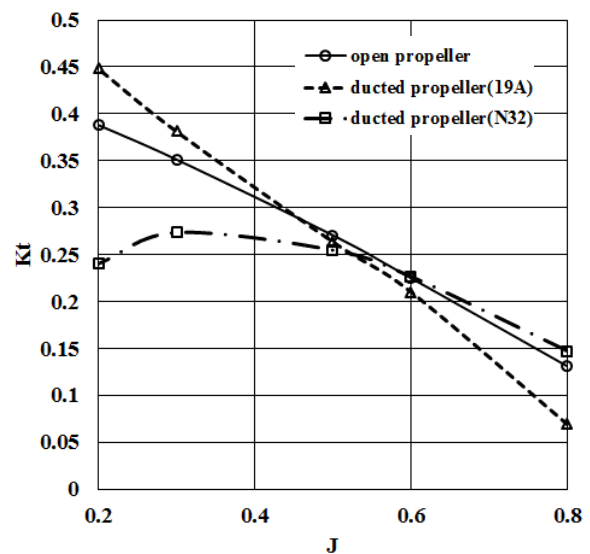


Figure 8. Total thrust coefficient comparison of ducted propellers

According to Figure 8, the 19A ducted propeller can efficiently operate in lower advance ratios (< 0.45) by increasing the total thrust. The 19A force on the flow is in the same direction with the propeller and overcomes nozzle-drag force. Eventually, the summation of the propeller and 19A permanent thrusts was more than the open-propeller thrust near the bollard condition. The highest percentage of the thrust increase is 15.5 percent at $J = 0.2$, extracted from the numerical computations. The N32 ducted propeller, however, operates in the opposite direction of the accelerating 19A duct. Moreover, it can also be observed that the total thrust increase of 12.1 percent occurred in $J = 0.8$, in which the 19A propulsive thrust is about 47 percent less than the open-propeller thrust. Accordingly, by considering open-water

efficiency alone for both ducts, the 19A duct in combination with the 5-blade propeller is appropriate for heavy conditions like trawlers, while the N32 ducted propeller is effective for higher advance ratios like torpedoes.

Distribution of pressure coefficient for the propeller blades and ducts

In this section, the chordwise-pressure-coefficient distribution of the propeller and ducts has been plotted. As the numerical solution, the steady-state accurate computations using the open-water procedure are considered so that the pressure-coefficient distributions are determined in three radial sections

of the propeller blade ($x = 0.3, 0.7, 0.9$). The results have been given for extreme conditions near the bollard one ($J = 0.2$) at the first level and $J = 0.8$ in the next step. Figure 9 illustrates the comparison of pressure-coefficient distribution of the blade at $x = 0.3, 0.7, 0.9$ for the 19A ducted propeller in 0.2 advance ratio; similar graphs for $J = 0.2$ are shown in Figure 10. From Figure 10, it can be seen that for all the x values, a sudden pressure increase happened due to the entrance of the blade's leading edge into the uniform flow and its impact on the uniform flow. As the distance to the root section increases, the peak pressure rises, considering constant speed of advance velocity.

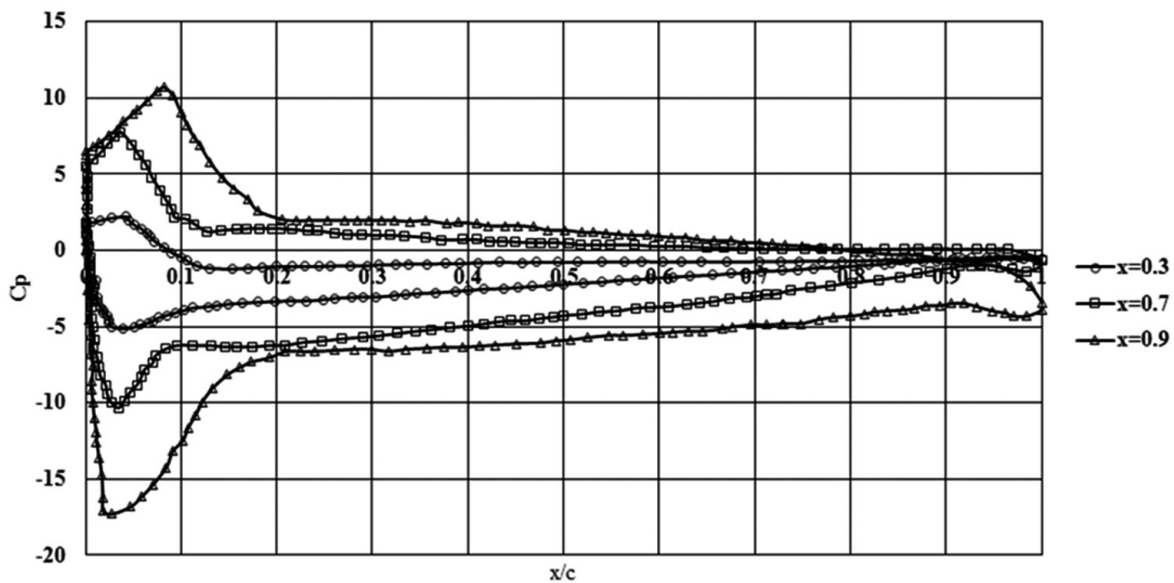


Figure 9. Pressure coefficient comparison of the 19A ducted propeller blade ($J = 0.2$)

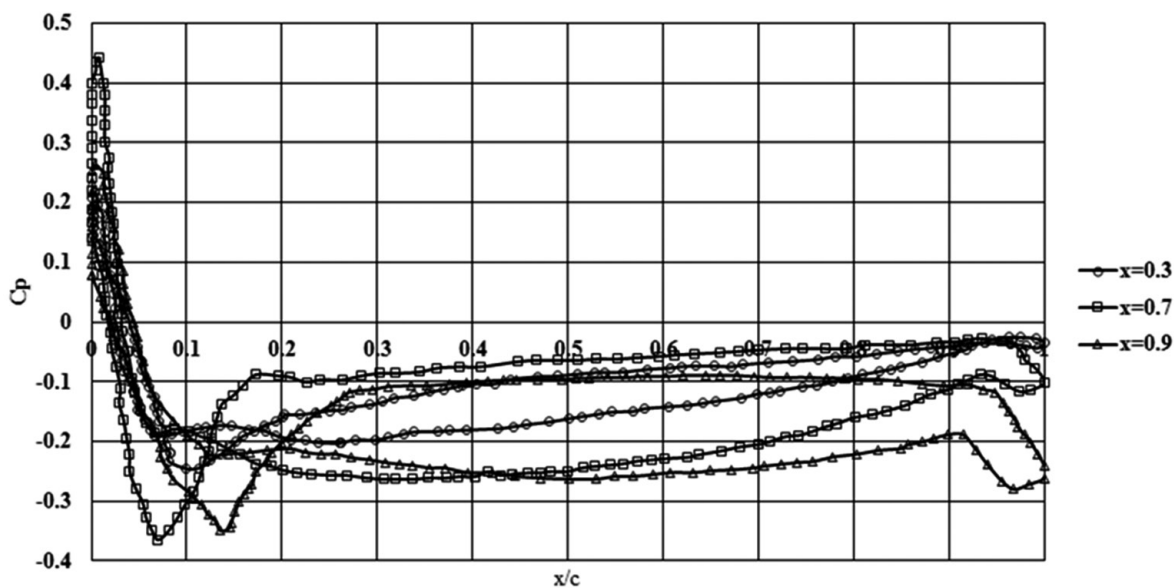


Figure 10. Pressure coefficient comparison of the 19A ducted propeller blade ($J = 0.8$)

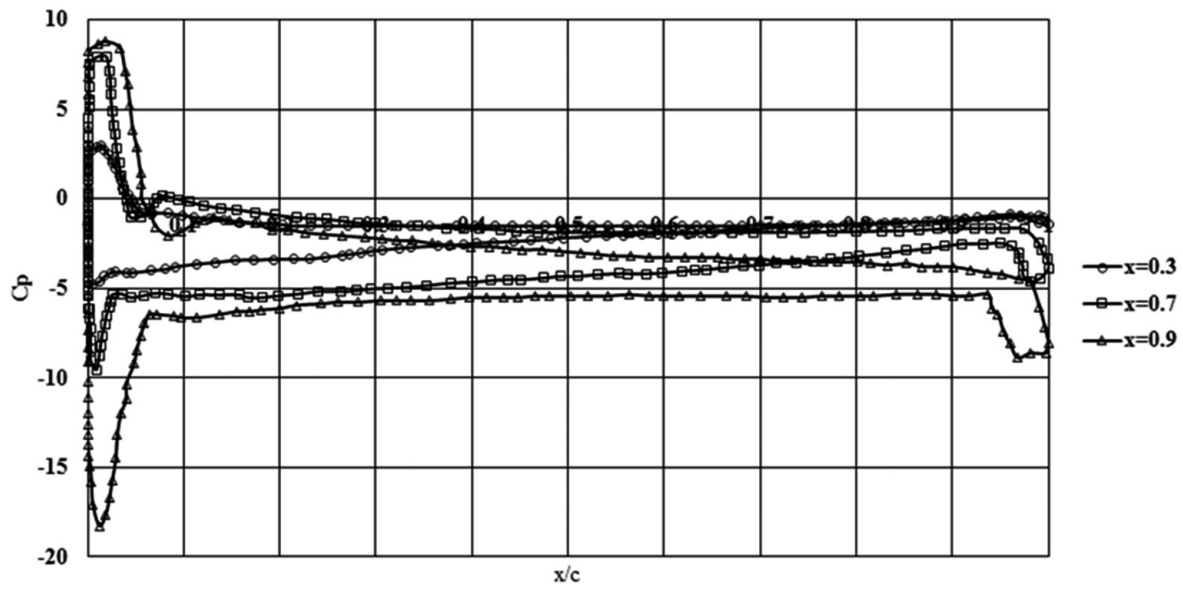


Figure 11. Pressure coefficient comparison of the N32 ducted propeller blade ($J = 0.2$)

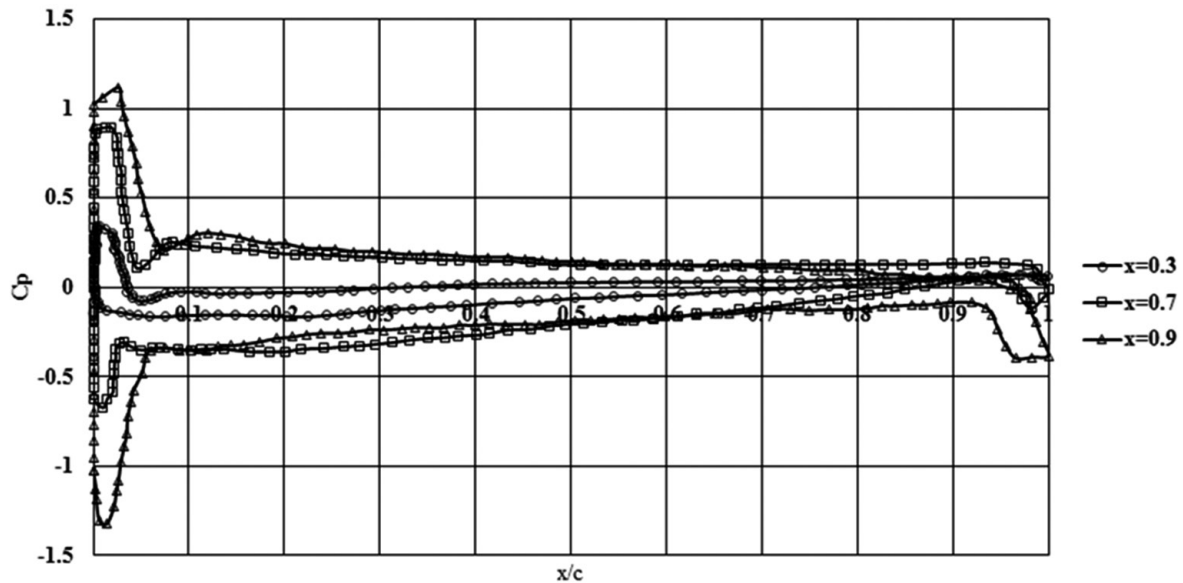


Figure 12. Pressure coefficient comparison of the N32 ducted propeller blade ($J = 0.8$)

Moreover, similar numerical studies have also been performed for the N32 ducted propeller and the obtained results are presented in Figures 11 and 12 for advance ratios of 0.2 and 0.8, respectively.

Concerning the negative-pressure fluctuations in the aforementioned figures and due to a higher propeller-thrust magnitude for the duct 19A than N32 in $J = 0.2$, the total pressure-coefficient distributions of the propeller blade are illustrated in Figure 13.

The similar numerical calculations have been implemented for an advanced ratio of 0.8, shown in Figure 14.

Based on the numerical analyses, the propeller inside the duct N32 produces more thrust than the

duct 19A in $J = 0.8$. This is mainly due to the greater discrepancy between pressure coefficients on pressure and suction sides of the blade in the N32 duct. Figure 15 presents the comparison of pressure-coefficient distributions on the two ducts for $J = 0.2$. From this figure, it can be observed that there is almost a significant difference between the 19A profile-section peak pressure which occurs near the leading edge, unlike the N32.

Pressure contours

Besides the above presented applications, in this subsection, the pressure contour of the ducted

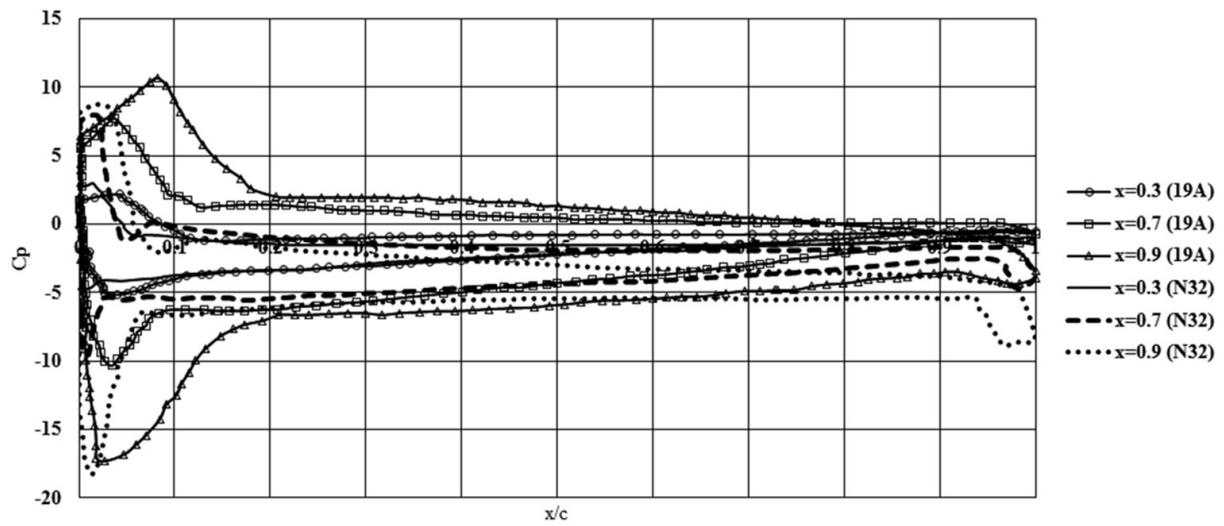


Figure 13. Comparison of the two ducted propeller blade pressure coefficient ($J = 0.2$)

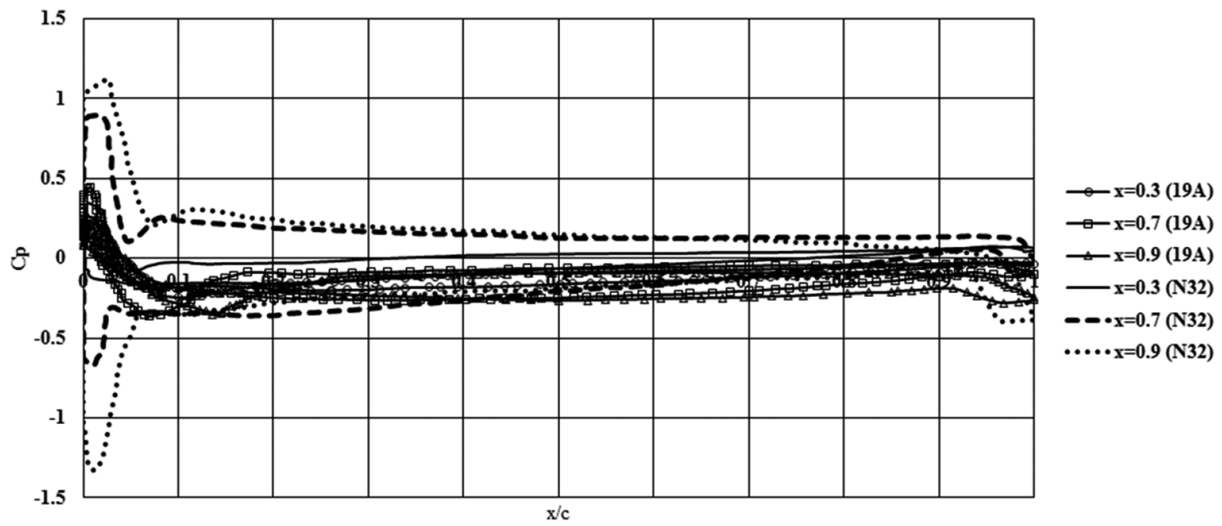


Figure 14. Comparison of the two ducted propeller blade pressure coefficient ($J = 0.8$)

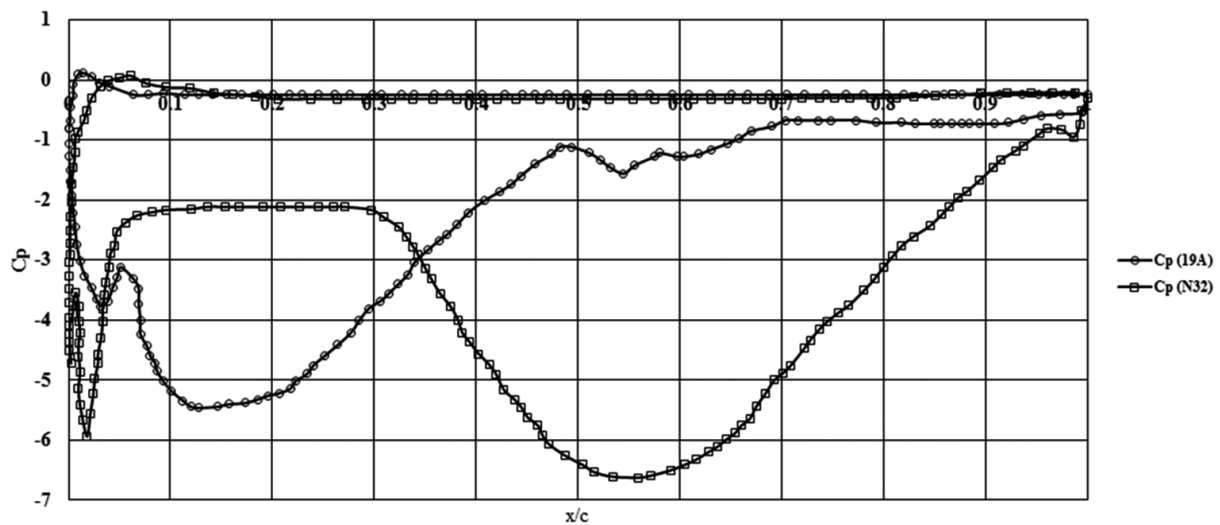


Figure 15. Comparison of the pressure coefficient distribution on ducts ($J = 0.2$)

propellers is illustrated for the back and face of the ducted propellers. In this regard, the side-pressure distribution of both of the ducted propellers' flow field is depicted. The pressure distribution for both back and face sides of the 19A and N32 ducted propeller are illustrated in Figures 16 and 17, respectively. In both ducted propellers, the back pressure is greater than the face one and because of this difference, the propeller thrust is formed.

For the blade tip, because of the pressure jump shown in the blade profile's pressure-coefficient distribution, an instantaneous pressure increase is significant for the propellers.

The flow-field pressure contours containing upstream, the blades back and face and downstream which explains the working and numerical arrangement of the ducted propellers are shown in Figure 18 for both accelerating and decelerating ducts.

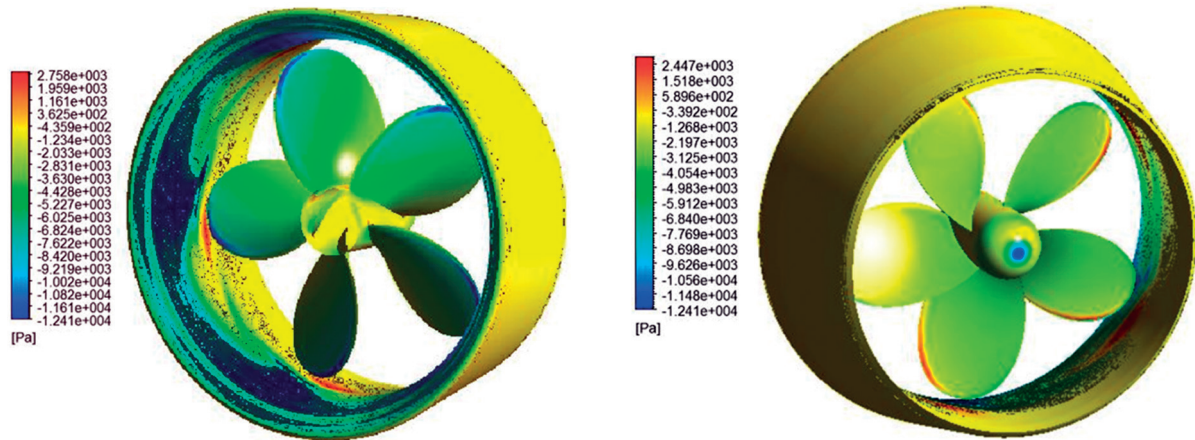


Figure 16. Pressure distribution of the blade surface and the 19A duct ($J = 0.2$)

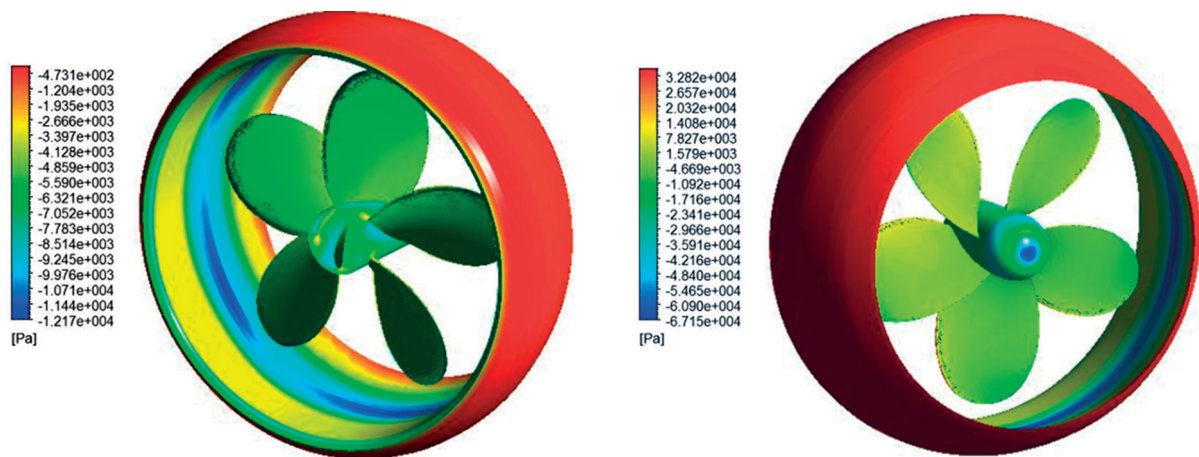


Figure 17. Pressure distribution of the blade surface and the N32 duct ($J = 0.2$)

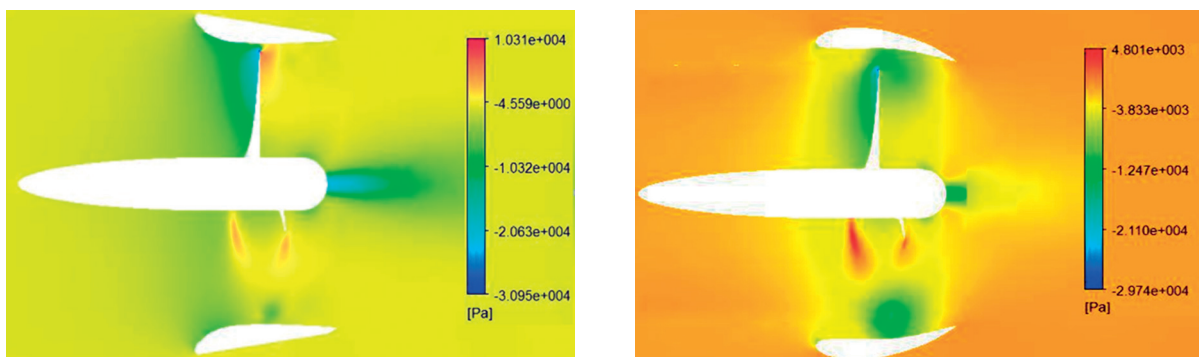


Figure 18. Flow field pressure contour of the 19A and N32 ducted propeller mechanism ($J = 0.2$)

From the pressure contours, it can be seen that the relative pressure at the back of the propeller is more negative than the face so that the back absolute pressure is lower than the face, which results in the thrust in the bossing direction.

Conclusions

In this paper, the effects of the two types of ducts, namely accelerating and decelerating, in combination with a 5-blade propeller have been investigated. The main findings of this research can be summarized as follows:

- From the open-water, hydrodynamic characteristics results, it was observed that the presence of the 19A ducted propeller improved the characteristics of the propeller, while the N32 ducted propeller showed a negative effect on the characteristics. Furthermore, for free, higher-advance ratios, the N32 ducted propeller is suitable and can increase the thrust up to 13 percent, compared with the open-water propeller conditions.
- In moderate conditions ($J = 0.5$), the presence of both ducts had no positive effect on the propulsive thrust. At higher revolutions, in addition, summation of the 19A duct and the blade's thrust was more than the open propeller one. In these conditions, the two ducts thrust was in the same direction as the propeller. In this regards, the total thrust drop of the 19A ducted propeller in $J = 0.8$ was greater than the total thrust drop of the N32 ducted propeller in $J = 0.2$.
- Considering the obtained pressure-coefficient distribution, it was observed that as the distance to the root section increases, both the peak pressure and the leading edge pressure increase. Moreover, it was also found that the pressure coefficient in the suction side of the blade profile was negative.
- Finally, and based on the obtained flow-field pressure contours for the two ducted propellers, it was demonstrated that the lower pressure is always in the back side of the propeller in absence of the ducts. However, based on the contours, adding the ducts has opposite effects on the pressure distribution around the propellers. To be more precise, the accelerating ducts, 19A, will cause more negative pressures in the back side while the N32 type, which is a decelerating one, will result in negative pressure fields in front of the propeller. Therefore, these findings can be applied by engineers for their design purposes.

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Mathematical models for simulation of layer hydrodynamics of a ship fluidized bed boiler

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Key words: two-phase flows, fluidized bed boilers, mathematical modeling, simulation, ship, swaying motion

Abstract

Fluidized bed boilers have been widely used for many years in energetics but their application in shipbuilding has been incidental. The hydrodynamics of a fluidized bed is a complicated issue. If the swaying of a ship on a sea wave is taken into account, this issue will be further complicated. The choice of an appropriate mathematical model is important from the viewpoint of building computer models for the simulation of a fluidized bed during disruptions that result from the ship swaying on sea waves. Fluidization is a two-phase flow process, which is described by many models such as the homogeneous-slip model or heterogeneous-slide model. The most popular models that show two-phase gas-solid or fluid-solid flow are the Euler-Euler and Euler-Lagrange models. The paper presents models that describe a ship's fluidized bed.

Nomenclature

C_D – drag force coefficient
 d – diameter
 F_d – drag force for a single particle
 g – specific gravity force
 F_i – external body force
 I – unit tensor
 K_{gs} – momentum exchange coefficient
 m_p – mass of particles
 p – pressure
 t – time
 V – volume of particles
 α – volume of phase
 ε – porosity of dense
 η – dynamic viscosity
 μ – shear viscosity
 ρ – density
 τ – shear stress tensor
 v – velocity

Subscripts

g – gas
 p – particle
 s – solid

Introduction

Fluidized bed boilers are being applied in many branches of industry, such as pharmaceutical, chemical, mineral-processing industrial, and metallurgy. They are also becoming increasingly popular in civil engineering; however, boilers with a circulating-fluidized bed displace boilers with a bubbling-fluidized bed because they have greater energetic efficiency and lower emission of nitrogen oxides (NO_x) (Bis, 2010). The phenomenon of fluidization, which in fact is a two-phase flow, is a complicated problem. A new problem, in the aspect of simulation modeling of layer hydrodynamics of a ship fluidized-bed

boiler, is consideration of external disturbances such as the swaying of a ship that affects the process of fluidization. This paper presents mathematical models describing the process of fluidization that are taken into account in the aspect of selection of the most appropriate model that will allow for easy adaptation while allowing for consideration of the aforementioned disturbances.

Mathematical models of two-phase flow

Two-phase flow is the common flow of two phases, continuous phase and dispersed phase, where continuous phase is a fluid or a gas and dispersed phase is the substance of any physical state. In the issue considered herein, the continuous phase represents gas and the dispersed phase will be represented by the particles of solid fuel, such as coal or solid biomass. A characteristic feature of two-phase flow is appearance of the surface of phase separation. The flow area can be treated like a space that is divided into two single-phase subareas by a boundary surface. Each of the individual phases can be formulated into an equation, like for single-phase flow. Models formulated in this way belong to the class of heterogeneous models (slide models). The second group is homogeneous models, in which each of components fill the whole volume and lose individual features, which means that both phases are treated as perfectly mixed and moving with the same velocity (slip model).

Commercial software for simulation of flow dynamics, called Computational Fluid Dynamic (CFD; for example, FLUENT), is used to create two types of mathematical models: the Euler-Euler model and Euler-Lagrange model. The approach to the simulation of two-phase flow in models mentioned above is different. In the Euler-Euler model, each phase in the mathematical approach is considered as continuous and fully interpenetrating, which may be based on the Navier-Stokes equation. Variables from the Euler equation are used in constitutive equations for all phases, while in Euler-Lagrange model, the Newton motion equation is used for each particle separately. This approach also takes into account a collision model to consider the energy dissipation caused by the non-ideal interactions of particles in the dispersed phase. The group models based on the Euler equation can be included in the Granular-Euler model. In the next part of the article, the above models will be broadly characterized (Huilin, Yurong & Gidaspow, 2003; Yang & Renken, 2003; Taghipour, Ellis & Wong, 2005; Benzarti, Mhiri & Bourhot, 2012).

Euler-Euler Model

The Euler-Euler Model is the most popular model in many types of software used for simulations and is the preferred model for simulation of a fluidized-bed layer. The basis for building the Euler-Euler Model equation is conservation of mass, energy, and momentum for each phase (Huilin, Yurong & Gidaspow, 2003; Lundberg & Halvorsen, 2008; Benzarti, Mhiri & Bourhot, 2012).

The mass conservation equations for the gas phase (g) and for solid phase (s) can be represented by the formula [14]:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g) + \nabla(\alpha_g \rho_g \bar{v}_g) = 0 \quad (1)$$

$$\frac{\partial}{\partial t}(\alpha_s \rho_s) + \nabla(\alpha_s \rho_s \bar{v}_s) = 0 \quad (2)$$

The momentum conservation equation for both phases can be presented as follows:

$$\begin{aligned} \frac{\partial}{\partial t}(\alpha_s \rho_s \bar{v}_s) + \nabla(\alpha_s \rho_s \bar{v}_s^2) = \\ = -\alpha_s \nabla p + \nabla \bar{\tau}_s + \alpha_s \rho_s \bar{g} + K_{gs}(\bar{v}_s - \bar{v}_g) \end{aligned} \quad (3)$$

$$\begin{aligned} \frac{\partial}{\partial t}(\alpha_g \rho_g \bar{v}_g) + \nabla(\alpha_g \rho_g \bar{v}_g^2) = \\ = -\alpha_g \nabla p + \nabla \bar{\tau}_g + \alpha_g \rho_g \bar{g} + K_{gs}(\bar{v}_g - \bar{v}_s) \end{aligned} \quad (4)$$

where:

α – volume of phase fraction,

ρ – density,

v – velocity,

p – pressure,

g – specific gravity force,

τ – shear stress tensor.

In adiabatic flows, the equation of energy conservation brings nothing new to the system of conservative equations and therefore is omitted. In many works, particular attention is paid to the drag force which is represented by the momentum-exchange coefficient K_{gs} . Depending on the model, it is variously formulated. For example, in the model proposed by Gidaspow, which is combination of two other models, Wen-Yu and Ergun (Orzechowski, 1990; Huilin, Yurong & Gidaspow, 2003; Benzarti, Mhiri & Bourhot, 2012), it is defined as follows:

$$K_{gs} = \frac{3}{4} C_D \frac{\alpha_s \alpha_g \rho_g |\bar{v}_s - \bar{v}_g|}{d_s} \alpha_g^{-2.65} \quad (5)$$

for $\alpha_g > 0.8$

$$K_{gs} = 150 \frac{\alpha_s^2 \mu_g}{\alpha_g d_s^2} + 1.75 \frac{\alpha_s \rho_g |\vec{v}_s - \vec{v}_g|}{d_s} \quad (6)$$

for $\alpha_g \leq 0.8$

where:

$$C_D = \begin{cases} \frac{24}{\alpha_g \text{Re}_s} [1 + 0.15(\alpha_g \text{Re}_s)^{0.687}], & \text{Re}_s < 1000 \\ 0.44, & \text{Re}_s > 1000 \end{cases} \quad (7)$$

$$\text{Re}_s = \frac{\rho_g d_s |\vec{v}_s - \vec{v}_g|}{\mu_g} \quad (8)$$

where:

C_D – drag force coefficient,

d – diameter,

μ – shear viscosity,

Re – Reynolds number.

For closure of the system of equations that creates the mathematical model, there are also needed constitutive equations that are relations between stress-state and strain-state tested material. The stress tensor is calculated based on the sum of all average values of velocities according to the Navier-Stokes equation (Kozic et al., 2011).

Granular-Euler Model

The Granular-Euler Model is another model from the group of mathematical models describing the phenomenon of two-phase flow. This model is used when the motion of particles is determined by mutual collisions. Collision of particles with the walls is also taken into account in this model.

The continuity equation of the granular phase (in this case there is no separation on a solid phase and gas phase) is represented by equation (9) (Bakker, 2008):

$$\frac{\partial}{\partial t} (\alpha_s \rho_s) + \nabla (\alpha_s \rho_s \vec{v}_s) = \dot{m}_{fs} \quad (9)$$

where: \dot{m} – mass stream.

The momentum-conservation equation, similar to the Euler-Euler Model, looks as follows (Bakker, 2008):

$$\begin{aligned} & \frac{\partial}{\partial t} (\alpha_s \rho_s \vec{v}_s) + \nabla (\alpha_s \rho_s \vec{v}_s \vec{v}_s) = \\ & = -\alpha_s \nabla p_f + \nabla \bar{\tau}_s + \sum_{s=1}^n (\bar{R}_{fs} + \dot{m}_{fs} \vec{v}_{fs}) + \bar{F}_s \end{aligned} \quad (10)$$

wherein: $-\alpha_s \nabla p_f$ – fluid pressure (gas); $\nabla \bar{\tau}_s$ – solid stress tensor; $\sum_{s=1}^n (\bar{R}_{fs} + \dot{m}_{fs} \vec{v}_{fs})$ – phase interaction term.

The granular-temperature equation – an equation implemented in the Granular Model, which is proportional to the kinetic energy of the random motion of the particles – looks as follow (Bakker, 2008):

$$\begin{aligned} & \frac{3}{2} \left[\frac{\partial}{\partial t} (\alpha_s \rho_s \Theta_s) + \nabla (\alpha_s \rho_s \Theta_s \vec{v}_s) \right] = \\ & \bar{\tau}_s : \nabla \vec{v}_s + \nabla (k_{\Theta_s} \nabla \Theta_s) - \gamma_s + \phi_{ss} + \phi_{gs} \end{aligned} \quad (11)$$

where: $\bar{\tau}_s : \nabla \vec{v}_s$ – generation of energy by the solid stress tensor; $\nabla (k_{\Theta_s} \nabla \Theta_s)$ – diffusion of energy; $\phi_{ss} + \phi_{gs}$ – represent the energy exchange among solid phase (ss) and exchange between gas and solid phase (gs).

To solve the complete granular-temperature equation, Syamlal proposed an algebraic form to this equation (Benzarti, Mhiri & Bourhot, 2012). He assumed that the energy of the granular phase is steady state and dissipates locally, which is why convection and diffusion terms can be neglected. Equation (11) can be represented as:

$$0 = (-P_s I + \tau_s) : \nabla v_s - \gamma \quad (12)$$

where: γ – dissipation of energy due to inelastic collisions.

The basic difference between the momentum-conservation equation in the Euler-Euler Model (3, 4) and that of the Granular-Euler Model (10) is the presence in the first of them two equations that show the momentum-conservation equation separately for the gas phase and solid phase, while in the Granular-Euler Model there is only a single equation; another difference is the presence of a momentum-exchange coefficient mentioned above. In the second of them an interaction is described between phases that is compared to zero, with present balance between states. This model is based on the kinetic theory of gases, which makes it difficult to apply to the computer simulations because there is needed a heat-exchange analysis and mass-exchange analysis between phases.

Euler-Lagrange Model

The Euler-Lagrange Model approaches the problem differently than the Euler-Euler Model. For the solid phase, there are equations of energy balance while the dispersed phase is treated like a set of

single particles, in which each of them is described using Lagrange's variables – variables of motion for the single particle. This theory mainly concerns hydrodynamics of molecules and it can be applied where is a small quantity of particles (Di Felice & Kehlenbeck, 2000; Kudela & Lewtak, 2002; Huilin, Yurong & Gidaspow, 2003; Lundberg & Halvorsen, 2008; Benzarti, Mhiri & Bourhot, 2012). Accepting the assumptions of the Euler-Lagrange Model that each particle is treated separately and for each of them there is a determined trajectory of motion using the Newton motion equation, the equation of Euler-Lagrange Model can be represented as follows (Sobieski, 2009):

For the continuous phase:

- continuity equation:

$$\frac{\partial(\varepsilon\rho_g)}{\partial t} + \varepsilon\rho_g\bar{v}_g = 0 \quad (13)$$

- momentum equation:

$$\begin{aligned} \frac{\partial(\varepsilon\rho_g)}{\partial t} + \nabla\varepsilon\rho_g\bar{v}\bar{v} = \\ = -\varepsilon\nabla p - \varepsilon\nabla\bar{\tau}_g + \varepsilon\rho_g\bar{g} - \frac{1}{V_p} \sum_{i=1}^{N_p} \left[\frac{K_{gs}V_p}{1-\varepsilon} (\bar{v}_g - \bar{v}_p) \right] \end{aligned} \quad (14)$$

For the dispersed phase:

To describe the dispersed phase using the Lagrange approach, it is necessary to take into account the huge quantity of particles and treat them like a set of particles described using a series of differential equations:

- location of particle:

$$\frac{\partial\bar{x}_p}{\partial t} = \bar{v}_p \quad (15)$$

- velocity of particle:

$$m_p \frac{\partial\bar{v}_p}{\partial t} = \sum \bar{F}_i \quad (16)$$

- angular velocity of particle:

$$I_p \frac{\partial\bar{\omega}_p}{\partial t} = \bar{T} \quad (17)$$

where:

ε – porosity of fraction,

V – volume,

F_i – external body force,

m – mass.

In the Euler-Lagrange Model, the equation of motion is solved for each particle separately, which requires considerable computing power. During

equation solving, also considered is the energy dissipation caused by the non-ideal interactions of particles.

Foscolo-Gibilaro and Richardson-Zaki Model

Analyzing the behavior of the fluidized bed also allows for the Foscolo and Gibilaro Model to be used (Joseph, 1990; Lattieri et al., 2001; Lundberg & Halvorsen, 2008). In this model, it is assumed that the layer is built of two continuous ones penetrating each other from the gas phase and phase of solid particles. Both phases are treated as incompressible.

The conservation equations in the Foscolo-Gibilaro Model, written as one dimensional, are represented as (Joseph, 1990):

- mass conservation equation:

$$\frac{\partial\varepsilon}{\partial t} + \frac{\partial(\varepsilon v_g)}{\partial z}, \text{ for fluid} \quad (18)$$

$$\frac{\partial(1-\varepsilon)}{\partial t} + \frac{\partial((1-\varepsilon)v_p)}{\partial z}, \text{ for particles} \quad (19)$$

- momentum conservation equation:

$$\begin{aligned} \frac{\partial\varepsilon}{\partial t} + \frac{\partial(\varepsilon v_g)}{\partial z} \varepsilon\rho_f \left(\frac{\partial v_g}{\partial t} + u_f \frac{\partial v_g}{\partial z} \right) + \\ + \varepsilon\rho_g g + F_I + \frac{\partial p_g}{\partial z} = 0, \text{ for fluid} \end{aligned} \quad (20)$$

$$\begin{aligned} (1-\varepsilon)\rho_p \left(\frac{\partial v_p}{\partial t} + u_p \frac{\partial v_p}{\partial z} \right) + (1-\varepsilon)\rho_p g + \\ - F_I + \frac{\partial p_p}{\partial z} = 0, \text{ for particles} \end{aligned} \quad (21)$$

where F_I is the strength of interaction between the fluid and particle. Force is the sum of the contribution: drag force and buoyancy force for a single particle.

Buoyancy force in this model looks as follows:

$$F_d = \frac{\pi d_p^3}{6} (\rho_u - \rho_g) g \left[\frac{v}{v_p} \right]^{\frac{4.8}{n}} \varepsilon^{-3.8} \quad (22)$$

where: $v = v_p \varepsilon^n$; v_p – terminal fall velocity.

Coefficient n depends on the Reynolds number and in correlation proposed by Richardson-Zaki: $n = n(\text{Re}_t)$:

$$\begin{cases} n = 4.8 & \text{for } \text{Re}_t < 0.2 \\ n = 4.6 \text{Re}_t^{-0.03} & \text{for } 0.2 < \text{Re}_t < 1 \\ n = 4.6 \text{Re}_t^{-0.1} & \text{for } 1 < \text{Re}_t < 500 \end{cases} \quad (23)$$

where:

$$\text{Re}_t = \frac{d_p \rho_g v_t}{\mu_g} \quad (24)$$

Conclusions

Mathematical modeling of fluidized-bed layers is a complicated issue, due to complexity of the phenomenon of two-phase flow. The choice of mathematical models needs to be fitted to the assumed simulation conditions, such as the diameter of particles and the concentration of the material.

For the purposes of simulation of the fluidized-bed boiler, where there are additional forces caused by a swaying ship on a wave, it is recommended to simplify the model while maintaining the highest accuracy. If in the model, forces acting on other particles are not considered, the best model will be the Euler-Euler Model; this is a model with the widest range of applications. The model treats each of the phases separately, like a continuous phase, facilitating work and in preparing simulation. Another selection criterion is the adoption of an appropriate model for the description of the momentum-exchange coefficient. In this case, there are also several possibilities that can be distinguished by the model proposed by Gidaspow, or models by Sinclair or Syamlal-O'Brien, not described here. These models differ from each other in coefficients that are taken into account, where dividing is based on the volume fraction of the fluidized column that is filled with gas. The Gidaspow Model is a model that is the best in the case of a simulation of dense fluidized-bed layers. The Sinclair Model is a model that is applicable when the simulation concerns linear pneumatic transport (Bakker, 2008).

Homogeneous models may be especially useful where the motion of a single particle, in a two-phase mixture, is not analyzed and the most important parameter to be determined is drag forces of the mixture. In this study, we used averaged values of the continuous phase and dispersed phase that reduces the complexity of the model and calculations.

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Navigation and Maritime Transport

Extensible event stream format for navigational data

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Key words: eXtensible Event Stream, XES standard, process mining, navigational data, data mining, modeling, XML

Abstract

The eXtensible Event Stream (XES) format is a new approach to illustrate the process data. Every ship journey is a sequence of some activities which can be read using different sources of data such ARPA, AIS etc. So we can say that this is a kind of process and its data can be organized in ordered and simple form. The most popular data formats to show the process data were of course XML and CSV. Currently, we can observe huge progress in the domain of process mining. Every year, new tools appeared and the need for some data standard became necessary. This standard is called Extensible Event Stream. In this paper, the use of XES format in navigational data is described.

Introduction

Modern data analysis requires suitable tools, such as software, methodology etc. Data can be acquired in different forms and from a variety of sources. The type of data is significant for further research and interpretation. The experiences of data scientists showed that the format of the data is the most important factor for success in data analysis (Aalst, 2011).

The same fact can be observed in the context of process mining. A few years ago the main file formats in this field were XML and CSV files. XML is a natural way to express the dependencies in the data and is still used today. This format is very widely used by software developers, scientists and more. CSV is a nice way to create a spreadsheet in MS Excel. It does not even require having MS Office installed. It is easy to use and send through the network. This is only the simple text file which contains the table of data. The last few years of research in process mining resulted in the creation of a new XML-based data format – eXtensible Event Stream (XES). The XES Working Group has mainly been established thanks to the Technical University of

Eindhoven (The Netherlands). XES became the official IEEE standard (www.xes-standard.org).

The main features

The most important thing in process mining is the event logs – the basic form of the data. It contains the information about the process, such as timestamp, activities, resources, comments etc. The event log is the description of the process recorded during its life cycle. The natural way to express this kind of data was with CSV and XML formats, but could not show the desired structure of the process. The new XES data format (see UML diagram in Figure 1) is works better due to numerous advantages:

- Simplicity – the simplest possible way to represent the information about the process.
- Flexibility – the standard is able to capture event logs from any background.
- Extensibility – it must be easy to add some features to the standard in the future.
- Expressivity – the loss of the information should be as low as possible, so all information elements must be strongly typed. It must be easy for others to interpret the information.

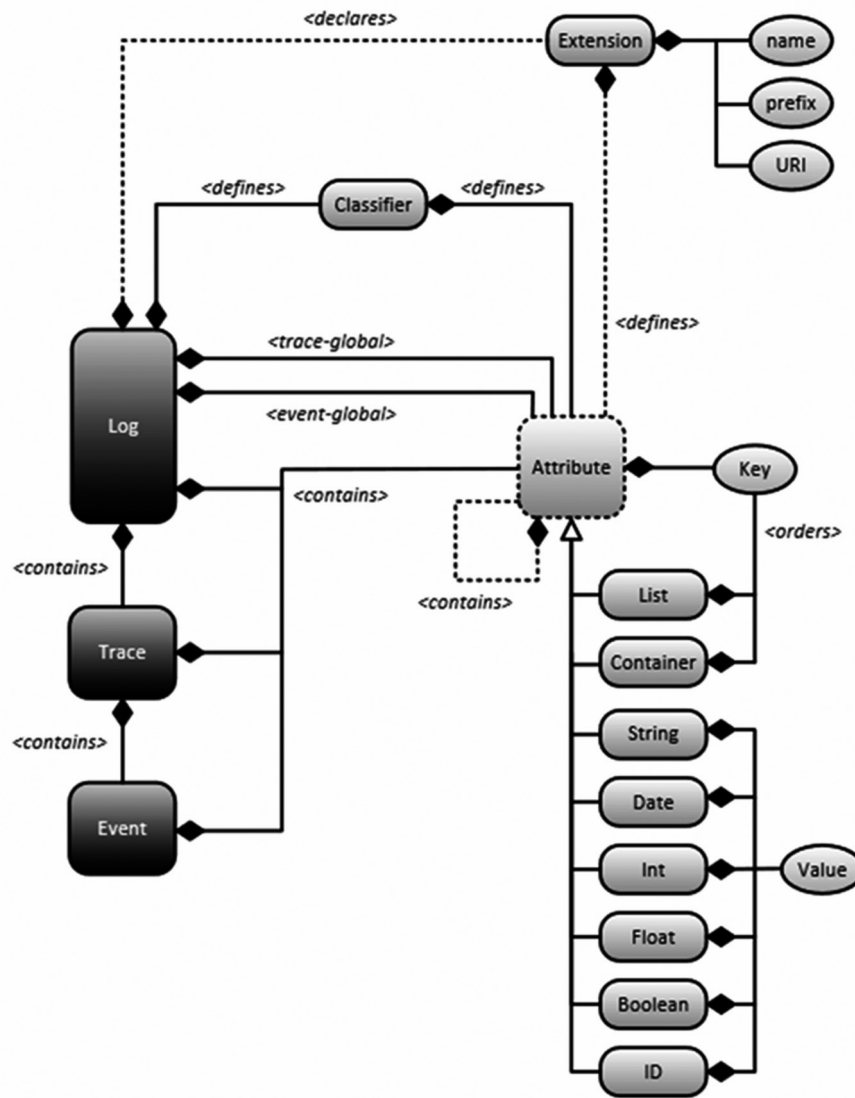


Figure 1. The UML diagram of XES format (source: www.xes-standard.org)

Why is XES data format so important? The reason is obvious and simple. The majority of tools used in process mining support mainly this kind of

data (ProM, Disco). Indeed, some of them are able to convert the event log to XES, generally it is recommended to use only this format.

Table 1. An example event log (Aalst, 2011)

Case id	Event id	Properties			
		Time stamp	Activity	Resource	Cost
1	3654423	30-12-2010:11.02	Register request	Pete	50
	3654424	31-12-2010:10.06	Examine thoroughly	Sue	400
	3654425	05-01-2011:15.12	Check ticket	Mike	100
	3654426	06-01-2011:11.18	Decide	Sara	200
	3654427	07-01-2011:14.24	Reject request	Pete	200
2	3654483	30-12-2010:11.32	Register request	Mike	50
	3654484	30-12-2010:12.12	Check ticket	Mike	100
	3654485	30-12-2010:14.16	Examine casually	Pete	400
	3654486	05-01-2011:11.22	Decide	Sara	200
	3654487	08-01-2011:12.05	Pay compensation	Ellen	200

The event log

The event log consists of some cases. These cases are the ordered sets of some activities (not always unique). Each activity has some attributes. The most important attributes are its timestamp and the identifier. Other attributes can represent other types of information – numbers, characters etc.

Where do the event logs come from? The event log can be recorded during the process, can be obtained from the organization etc. It can be also generated artificially (randomly) but it is necessary to look carefully at the accuracy of the data. Absences of data are not allowed. One cannot see the time of the process if does not have any timestamps. The activity cannot be identified if it does not have even the name or identifier. Of course some data can be ignored. If the information about the resources is not necessary, then it can be skipped in some situations. If data recovery is possible, it should be done before the process mining procedures.

In Table 1, a simple example fragment of the event log is given. Three main parts of it are clearly marked. Case id, event id and properties. The most important property is the timestamp. There is no event log without this element.

Navigational data

The facts mentioned above naturally lead to the following question: can we treat the ship’s motion along a given route as a process? The answer is, of course, yes. A ship is not only an object which moves from the departure point to the destination. There is a sequence of activities to reach the final port. Navigational data can be obtained in different ways. There

is a lot of equipment on board, such as AIS or ARPA. Moreover, there are some web services such Marine-traffic.com tracking the ships. In Dramski (Dramski, 2016) the α -algorithm was used to build a process model for a ship’s route. The data was obtained from the web and then transformed into an event log in XES format.

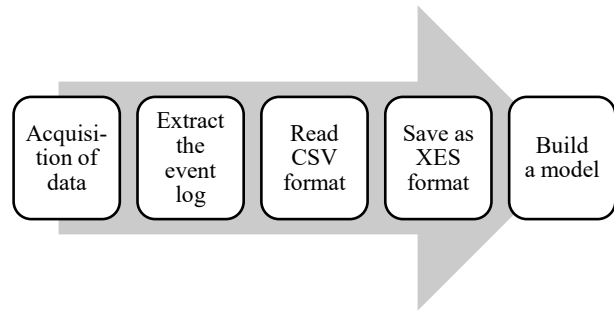


Figure 2. From data acquisition to the process model

Figure 2 illustrates all the necessary steps from the data acquisition to the process model. This time the process data was recorded using MS Excel and CSV files. Then the event log was extracted and saved in XES format using Python programming language.

Data conversion

What does the conversion look like? The sequence diagram in Figure 3 illustrates the job of the software created for this purpose.

The first step in creating a process model is the analysis process. This is the starting point of the whole procedure. Next, the event log is created and then the data is recorded. At the given point, the data recording is stopped, but the process can still work

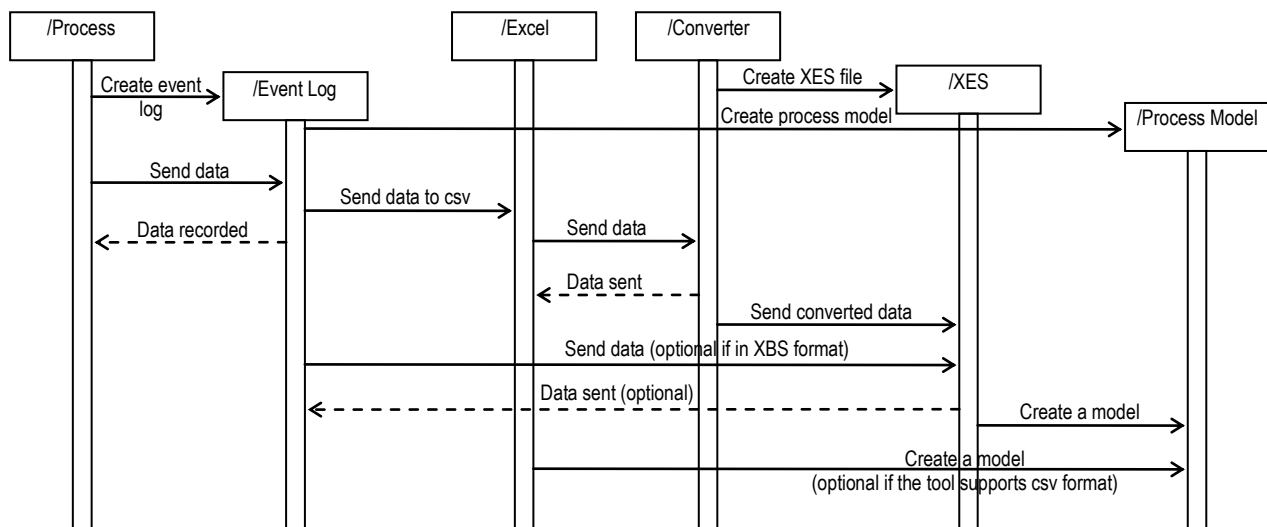


Figure 3. The sequence diagram of CSV to XES conversion

(it is not dependent on the model). Now we have two possibilities. If the recorded data format is CSV, it can now be sent directly to MS Excel, for instance, and some procedures can be carried out (e.g. in the case of data absences). If the data was originally recorded in XES standard, then it can be sent to the XES file and used for the creation of the model. However, let us go back to the situation where the CSV format is considered. The data needs to be converted and the converter is used. After the conversion the data can be sent to the XES file and, of course, used by the model.

In Figure 3 it can also be seen that the event log does not exist at the same time as the process. This is

natural and easy to explain. If we do not record data, the event log is not needed. The same situation is observed with an XES file. It does not exist if it is not created. The creation time comes after the converter's job has begun. In this diagram, it is also clear that no object is destroyed. The process exists in the time and it does not depend on any other object from the system. The same situation occurs with the Excel and converter objects. Evidently it can be assumed that the converter is not needed after the conversion, but it can still be used in the future.

In Figure 4 the real collected data from Marine-traffic.com is illustrated. Clearly, due to the large number of samples, the spreadsheet is limited to the

CaseID	EventID	TIME (UTC)	Event	Area	Port	Speed (kn)	Course (deg)	Lat (deg)	Lon (deg)
1 a		25.09.2015 07:45	In Range					53,51891	14,62613
1 f		25.09.2015 08:07	Underway			6,6	170	53,51163	14,62684
1 c		25.09.2015 08:16	Arrival		SZCZECIN				
1 h		25.09.2015 12:06	Midday position				248	53,43235	14,57165
1 d		25.09.2015 13:38	Departure		SZCZECIN				
1 e		25.09.2015 13:54	Stopped			0,4	283	53,51895	14,62619
1 g		25.09.2015 18:22	Midnight position				70	53,51894	14,62615
2 a		26.09.2015 15:49	In Range					53,51891	14,6262
2 f		26.09.2015 16:30	Underway			5,4	21	53,52082	14,62915
2 b		26.09.2015 16:41	Changed Course			5,4	343	53,53728	14,63026
2 b		26.09.2015 16:51	Changed Course			5,3	309	53,54886	14,61543
2 b		26.09.2015 17:35	Changed Course	Baltic Sea		5,1	350	53,60769	14,58788
2 b		26.09.2015 17:56	Changed Course	Baltic Sea		4,8	319	53,63425	14,57226
2 c		26.09.2015 21:53	Arrival		SWINOUJSCIE				
2 d		26.09.2015 23:00	Departure		SWINOUJSCIE				
2 g		26.09.2015 23:58	Midnight position	Baltic Sea		3,6	350	54,01335	14,261
3 a		27.09.2015 08:29	In Range	Baltic Sea		4,6	330	54,46527	13,86759
3 h		27.09.2015 12:08	Midday position	Baltic Sea		5,6	300	54,67297	13,54723
4 g		28.09.2015 00:08	Midnight position	Baltic Sea		6,2	272	54,51675	11,75235
4 c		28.09.2015 11:13	Arrival		NORD-OSTSEE-KANAL				
4 e		28.09.2015 11:24	Stopped	Kiel Canal		0,5	84	54,36821	10,14737
4 d		28.09.2015 11:24	Departure		NORD-OSTSEE-KANAL				

Figure 4. The collected navigational data in MS Excel

<pre>d = dict() for row in range(first_sheet.nrows): L = list() for column in range(first_sheet.ncols): L.append(first_sheet.cell(row, column).value) if (L[0] != "CaseID"): d[L[0]] = d.get(L[0],0) globalList.append(L) numberOfCases = len(d.keys()) for i in range(1,numberOfCases + 1): tmp = list() for j in range(1,first_sheet.nrows): if (globalList[j][0] == i): tmp.append((globalList[j][1],globalList[j][10])) d[i] = tmp</pre>	<p>Create global dictionary</p> <p>Read data from MS Excel file and make a global list (first_sheet variable contains the file path)</p> <p>Determine the number of cases</p> <p>Convert the global list and save it as a dictionary which will be the base for XES data format</p>
--	---

Listing 1. The fragment of CSV to XES converter in Python programming language

```

<?xml version="1.0" encoding="UTF-8" ?>
<log xes.version="2.0" xes.features="arbitrary-depth" xmlns="http://www.xes-standard.org/">
  <trace>
    <string key="CaseID" value="1" />
    <event>
      <string key="concept:name" value="a"/>
      <date key="time:timestamp" value="2015-09-25T07:45:00.000+00:00"/>
    </event>
    <event>
      <string key="concept:name" value="f"/>
      <date key="time:timestamp" value="2015-09-25T08:07:00.000+00:00"/>
    </event>
    <event>
      <string key="concept:name" value="c"/>
      <date key="time:timestamp" value="2015-09-25T08:16:00.000+00:00"/>
    </event>
  </trace>
  ...

```

Listing 2. The initial fragment of the XES file

first visible fragment from the screen. It is observed that some of the data is lacking. Empty fields do not always denote missing data because they can be easily updated. One of the MS Excel features is the possibility to export the data directly into CSV format. Unfortunately, MS Office does not support the XES format, so it is necessary to write a converter. This was done using Python (www.python.org) programming language. The most important part of the code is shown on the Listing 1.

The presented listing shows the main initial procedures of the converter's job. First of all there is a need to read the data from the MS Excel spreadsheet and then save it to a special data structure, being a combination of Python's list, tuple and the dictionary. At the end (not presented in this listing), the data is directly saved into XES format. The content of the XES file looks like on the Listing 2.

Listing 2 shows only the initial fragment of the final XES file. As aforementioned, the file structure is similar to XML, but the most important thing is that it can now be easily used to create a process model using process mining techniques and tools.

Conclusions

In this paper, the short description of the usability of XES file format for navigational data is shown. This data structure lets us treat the ship's route (or other processes related to marine industry) like a sequence of certain activities. The XES format

allows easy understanding of what the most important activities are; it shows the time of each activity and also can contain some other, maybe not always necessary, but usable information.

The research development in the process mining domain allows the creation of process models in every domain of the modern economy. Thanks to these tools, there are a lot of advantages, e.g. operational support (Dramski, 2015), which makes the predictions, or correction of some incorrect functionalities of the process, possible.

The XES data format makes the analysis of the process easier. It is supported by most tools, such as ProM or Disco.

Acknowledgments

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A method for reserve determination of the static and dynamic list of liquefied natural gas carriers and its application to the dynamic under keel clearance system in the outer port in Świnoujście

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Key words: dynamic UKC, simulation methods, analytical methods, list, pressure transmitters, LNG carrier

Abstract

This paper presents a methodology for determining the components related to the heel of liquefied natural gas (LNG) carriers, excluding the heel of the vessel due to waves. The described method was applied to the description of under keel clearance of vessels approaching the outer port of Świnoujście. The method includes the determination of heel components caused by: draught reading errors, wind, current, tugboats and vessel maneuvers. Determination of the last component was carried out using a 2-stage method. In the first stage, simulation methods were used to identify the parameters of ship movement. In the second stage, the maximum heel of LNG carriers was calculated by analytical methods.

Introduction

The inspection of a vessel's draught, list and heel is the basis for their exploitation, especially in the areas where the under keel clearance is limited. With exception to navigational safety, these considerations are mainly economic. Knowledge of the available under keel clearance directly affects the amount of cargo that can be carried. Shallow water areas, in addition to those clearly safe to pass, are taken into consideration in the analysis of the possible vessel route. It should be noted, however, that "shallow water" is a relative term, largely dependent on the size of the vessel which navigates within such areas. The shallow waters, which are known as restricted water areas, include, among others, harbors, dredged fairways, straits, and river or sea channels (Nowicki, 1999).

The following different sources of data are taken into consideration to determine a vessel's under keel clearance:

1. Width and available depth of the waterway;
2. Density of water;
3. Tides value;
4. Vessel LOA and breadth;
5. Vessel draught and displacement;
6. Vessel squat;
7. Weather conditions: wave height, wind speed and direction.

As mentioned above, there are many different variables which must be accounted for to calculate the vessel's under keel clearance. It is very important to determine them with high accuracy, especially the value of vessel draught, list and heel. Presently, these variables are identified with the use of numerous different methods. To provide safe navigation

and proper economical exploitation, it is necessary to have the ability to correctly assess their accuracy.

Systems and methods of vessel draught identification and their accuracy level

Measurements of vessel draught and list are among the most important pieces of information during navigation. On their basis, the stability of the vessel is determined. Nowadays, the readings of vessel draught can be carried out from several separate and independent sources such as:

- Draught marks located on the vessel's hull;
- Cargo loading program;
- Submersible pressure transmitters.

Due to the nature of draught accuracy, the readouts of measuring equipment are continuous. Comparison of draught value readouts from draught marks and cargo loading program is the most popular method of operation. These readings are considered as the most reliable.

Draught marks

The accuracy of draught identification depends on officer experience and sea state at the moment of reading. Although it is the oldest method, it is still

recognized as the one of the most accurate, giving the real value of vessel draught.

Cargo loading software

Cargo loading software (Figure 1), after its accreditation by classifiers, is the main source of vessel draught and list readouts and of the basis of its results the stability of the vessel is determined. Properly calibrated cargo loading software allows to term the parameters with an accuracy of less than 1 cm. The accuracy level depends on the quality of data transmitted from the radar sensor located in the tank. Possible errors, which can occur in radar sensors used in tanks of LNG carriers, are verified with the use of onboard measurement equipment (Whesoe gauge).

Pressure transmitters

The values of vessel draught and list are obtained from measure points and lines, located on the submerged, bow and stern parts of the hull, and also symmetrically on both sides at midship. The readout is inaccurate, with an error up to 5 cm at the beginning that increases over time. There are Different pressure transmitters with diverse accuracy are available on the market. Table 1 presents a selection

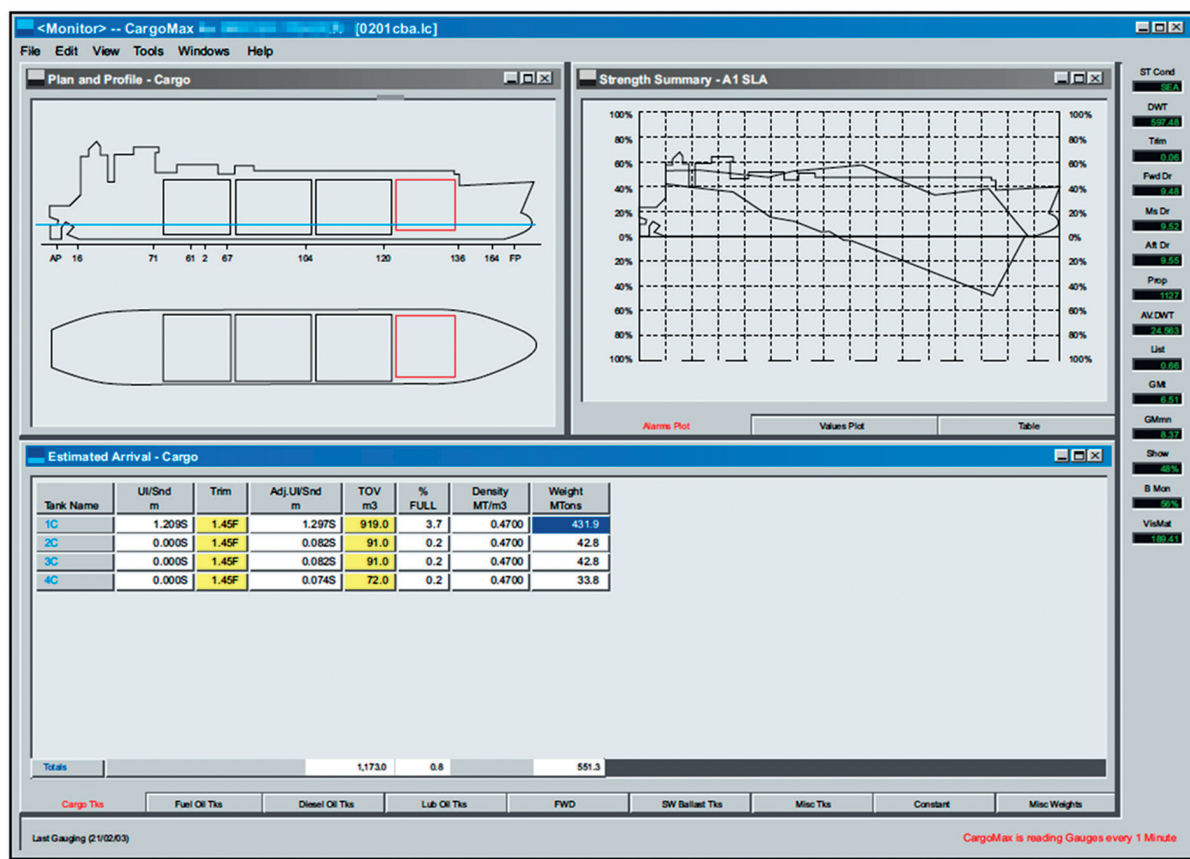


Figure 1. Screenshot of Kongsberg CargoMax (cargo loading software), showing the values of vessel draught and list

of the products most commonly installed on LNG carriers, along with their relative narrow measure error.

Table 1. Summary of accuracy level of selected pressure transmitters

Manufacturer	Product	Accuracy	Source
Vega	VEGAWELL52	< 0.1% FR	VEGA Grieshaber KG (2015)
Kongsberg	GT403	< 0.25% FR	Kongsberg Maritime AS (2009)
Besi	PESS	< 0.2% FR	BESI Armaturen GmbH & Co KG (2000)
A.P.I. Marine	UPT	0.2% FR	A.P.I. Marine ApS (2009)
Yokogawa	EJA120E	±0.2% FR	Yokogawa Electric Corporation (2015)
Validyne	DR800	±0.1% FR	Validyne Engineering (2015)

FR – full range [psi]

Systems and methods of vessel list identification

Vessel list, similar to the vessel draught, can be identified with the use of different methods, as below:

- Draught marks located at vessel midship;
- Inclinometer;
- Mathematical pendulum;
- Cargo loading software;
- Pressure transmitters.

Draught defined on the basis of marks located at the midship

The readout from draught marks, located at the midship, is considered to be one of the most reliable measures; however, for determining the vessel list or heel, it has a disadvantage. To identify the values, it is necessary to take the draught readouts from both sides of the hull at the same time. Due to that inconvenience the method is mainly used while vessel is in the shipyard or alongside. These readouts are compared with values obtained from other appliances available onboard.

Clinometer

This method is the most popular since it offers the fastest way to identify the vessel list and its stability (Figure 2). Because of its sensitivity, the device is mostly used during harbor loading operations. On the other hand, to get proper readouts of vessel list out of the port, calm sea conditions are necessary. During LNG carrier loading operations, due to

the many different external factors that can falsify readouts of list, the position of the vessel must be checked continuously. The external factors include waves caused by vessels passing nearby and slack of mooring lines.



Figure 2. Selected clinometers used onboard of LNG carrier (Sea shop, 2016; West Sea Company, 2016)

The mathematical pendulum is a very popular alternative to the clinometer in monitoring and comparing the vessel list. Its principle of operation is the same as the clinometer.

Pressure transmitters and cargo loading software

Pressure transmitters and cargo loading software are used in similar ways as in draught measurements (Figure 3).

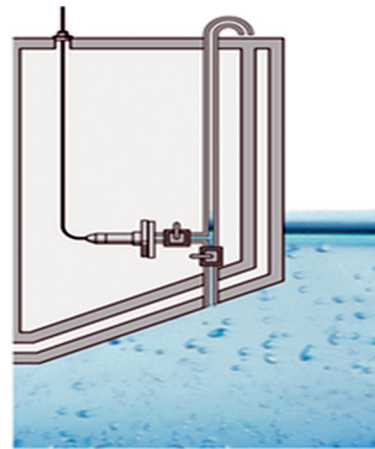


Figure 3. Typical application scheme of a pressure transmitter (Vega, 2016)

Reserve of constant list of LNG carrier ($\Delta 7$)

LNG carriers are equipped with auto-measurement systems of vessel list and/or heel (inclinometers), which offer the possibility of conducting fast and easy readouts. Compensation of constant list is achieved with the use of the vessel ballast system.

The list correction should also include:

- Constant list $\Delta 7_s$;
- Heel caused by wind $\Delta 7_w$;
- Heel caused by current $\Delta 7_p$;
- Heel caused by vessel turning $\Delta 7_z$;
- Heel caused by tugs $\Delta 7_h$.

The factors mentioned above should be taken into consideration in the future when modeling list. The correction models should also include the real states of external environmental conditions, because they represent 25% of the total reserve amount.

Constant list $\Delta 7_s$

The maximum reserve of constant list will not exceed 5 cm if the pressure transmitters, with maximum inaccuracy of 5 cm, are located at vessel midship.

Heel caused by wind $\Delta 7_w$

An accurate description of the environmental forces and moments is important in vessel simulators that are produced for human operators (Fossen, 2011).

To calculate the vessel heel caused by the wind, it is necessary to determine the lateral windage area, with the height of center point of the wind influence, direction and value of wind force. The following methods can be applied:

- 1) accurate method based on vessel stability data, including its righting lever curves $GZ = f(\varphi)$ for a given loading condition;
- 2) approximate method for minor vessel heel, where the location of its center of gravity, KG, must be known.

This paper presents calculations for a loaded LNG carrier with the use of the accurate method, since all necessary stability parameters are known.

The wind force F_w affecting the vessel at a height d_h , measured from the water surface, is shown in

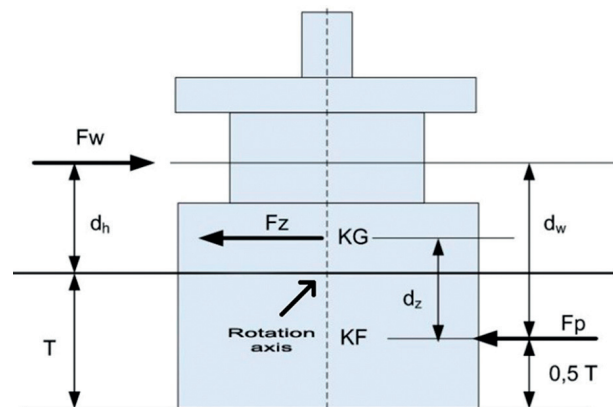


Figure 4. Parameters used in calculation of vessel heel caused by wind

Figure 4. The wind force lever arm, d_w , is calculated for the axis of rotation located between the center of gravity, KG, and the center of buoyancy, KF (which is 0.5 T). Based on vessel stability data and performed calculations, the correction of vessel heel caused by wind was determined (Table 2).

Table 2. Correction of LNG Qflex list caused by wind

Symbol	Value	Unit	Parameter
L_{pp}	300	m	length overall
B	50	m	breadth
T	12.5	m	draught
D	145200	T	displacement
KF	6.25	m	axis of rotation 0.5T = KF
d_h	13	m	height of center point of the wind influence counted from water surface
d_w	19.25	m	wind heeling arm from point of rotation (KF)
KG	17	m	center of gravity point
GM	5.3	m	intact metacentric height
d_z	10.75	m	distance counted from KG to KF
v_w	10	m/s	wind speed
ρ_p	1.226	kg/m ³	air density
ρ_w	1000	kg/m ³	water density
P_{w1}	4300	m ²	lateral windage area
C_{w1}	1.1	–	wind resistance factor of the hull
P_{w2}	2200	m ²	lateral windage area of tanks
C_{w2}	0.7	–	wind resistance factor of the tanks
P_{w3}	1000	m ²	lateral windage area of superstructure
C_{w3}	1	–	wind resistance factor of the superstructure
P_{ws}	7500	m ²	total lateral windage area
F_w	445651	N	wind force
F_w	45.4	T	wind force expressed in tones
M_w	874.493	Tm	wind heeling moment
$\sin(\varphi)$	0.00113	–	sinus of heeling angle $GZ = GM \cdot \sin(\varphi)$ for minor $\varphi = 0$ to 6 deg
φ	0.07	deg	constant vessel heel caused by wind
φ_d	0.13	deg	dynamic vessel heel
$\Delta 7_w$	0.06	m	correction of vessel heel caused by wind

The following formulas were used to calculate the correction of vessel heel caused by wind $\Delta 7_w$.

Wind heeling arm d_w :

$$d_w = (T - KF) + d_h \text{ [m]} \quad (1)$$

Distance d_z , measured from KG to KF:

$$d_z = d_w - KF \text{ [m]} \quad (2)$$

Wind force F_w (according to windage areas shown in Figure 5):

$$F_w = 0.5((P_{w1}C_{w1}) + (P_{w2}C_{w2}) + (P_{w3}C_{w3})) \cdot \rho_p \cdot v_w^2 \text{ [N]} \quad (3)$$

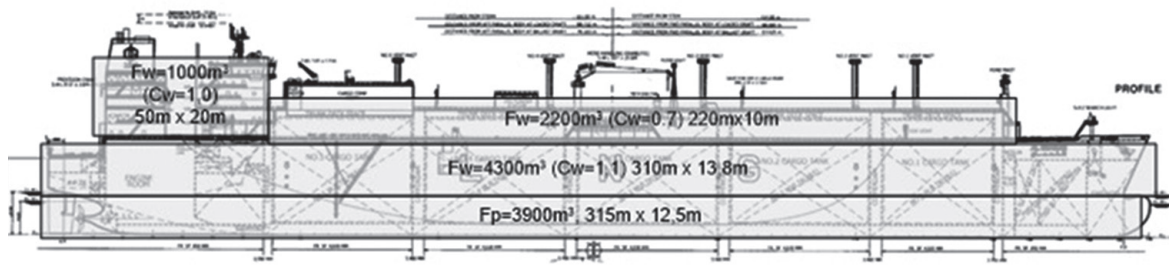


Figure 5. Lateral windage areas and wind resistance factors of Q-Flex type LNG carrier applied to calculations

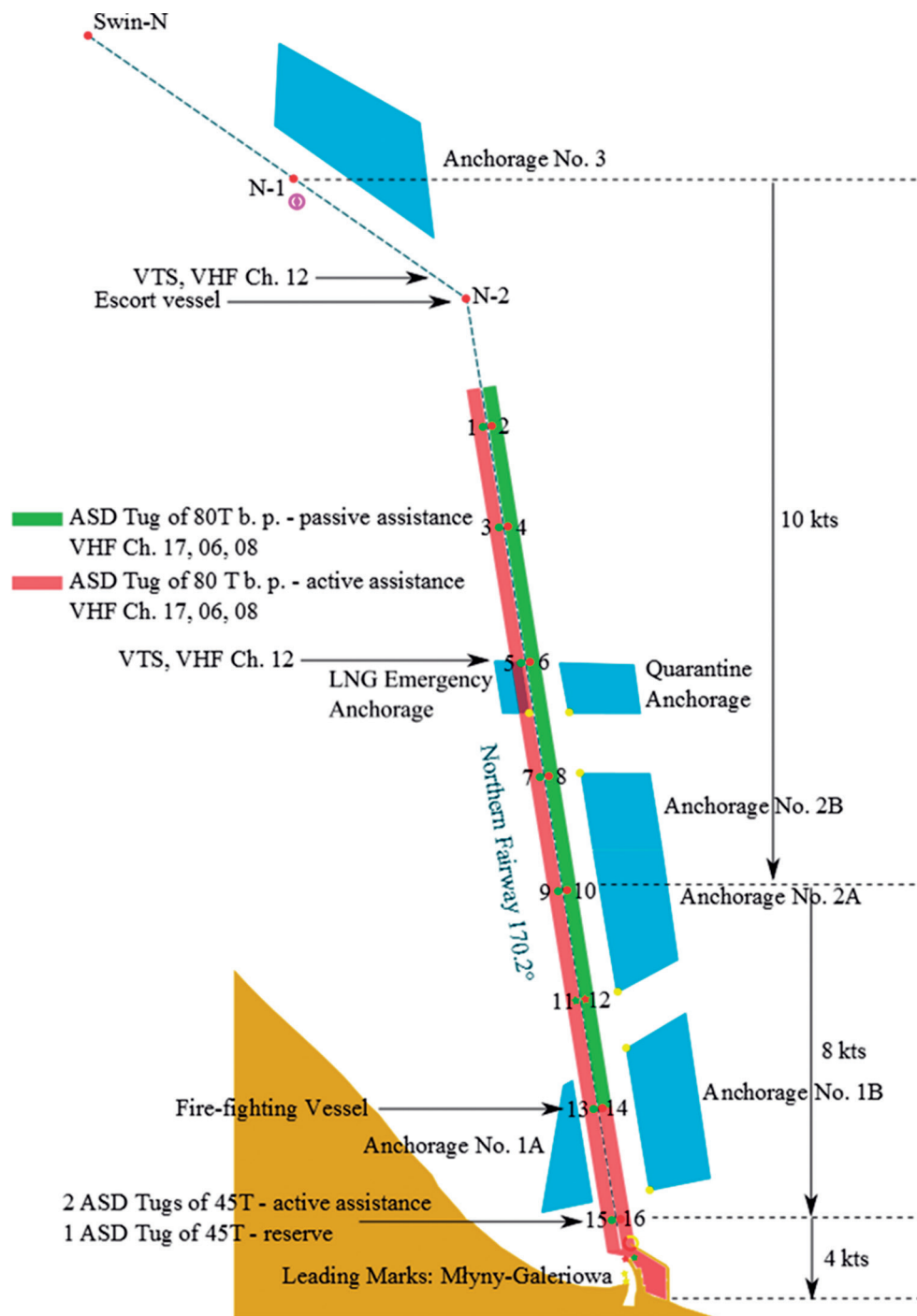


Figure 6. LNG carrier fairway to Outer Port of Świnoujście (Artyszuk, 2015)

$$F_w = 0.5 \sum (P_{wn} C_{wn}) \cdot \rho_p \cdot v_w^2 \text{ [N]} \quad (4)$$

Wind heeling moment M_w :

$$M_w = F_w \cdot d_w \text{ [Tm]} \quad (5)$$

Sinus of heeling angle $\sin(\varphi)$:

$$\sin(\varphi) = \frac{M_w}{GM \cdot D} \quad (6)$$

Dynamic vessel heel φ_d :

$$\varphi_d = 2 \varphi \quad (7)$$

Correction of vessel heel caused by wind $\Delta 7_w$:

$$\Delta 7_w = \frac{B \cdot \sin(\varphi_d)}{2} \quad (8)$$

The calculated value of vessel heel caused by wind is only 0.13 deg, which gives the correction $\Delta 7$ on the level of 0.06 m. According to stability documentation in that particular loading condition, the vessel list obtained for wind speed of 28 m/s is calculated at 1.3 deg.

Vessel heel caused by current $\Delta 7_p$

The vessel heel caused by current occurs only when a strong current rapidly affects the LNG carrier from the side. This comes when the vessel drift remains unstable (still changing). In practice, such conditions occur when the vessel passes the junction of channels, river estuaries and the like. Moreover, it should be noted that the torque caused by current takes on the minimum value. This is because the current force, F_p , affects the hull on the level of the axis of vessel rotation, i.e. in the vicinity of the center of buoyancy, KF, and is therefore negligible.

Vessel heel caused by vessel turning $\Delta 7_z$

The calculations described in this paper were carried out on the basis of simulation trials, which assumed the safe entry of the LNG Qflex carrier into the outer port of Świnoujście (Figure 6). The simulation was performed in the worst weather conditions allowing entrance in the port.

Turning at speed could be executed by using the rudder. When moving ahead, the ship rotates around the pivot point located in the front part of the ship (MacElrevey, 2004).

The standard deviation of the statistical sample S , which contained the rudder angles recorded during vessel pass from buoys 9–10 to 13–14, was calculated using following formula:

$$S = \sqrt{\frac{\sum (X - \bar{X})^2}{n - 1}} \quad (9)$$

where:

X – consecutive number of samples;

\bar{X} – arithmetic average;

n – total number of samples.

With the use of formula (9), the following was calculated:

$$S = 2.3 \text{ [}^\circ\text{]}$$

$$S(0.95) = 4.6 \text{ [}^\circ\text{]}$$

The standard deviation calculated for rudder angles with a level of confidence of 95%, can be defined as the interval (Figure 7):

$$S(0.95) = (-7, -2) \text{ [}^\circ\text{]}$$

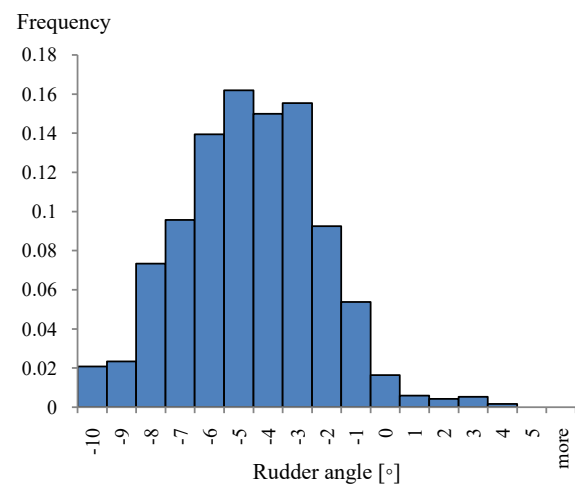


Figure 7. Rudder angle histogram for LNG Qflex carrier passing Świnoujście fairway from buoys 9–10 to 13–14

To determine the turning circle radius of the LNG Qflex carrier, it was necessary to carry out a simulation experiment, which assumed trials of starboard side, 180 deg turning, performed for selected rudder angles, with a start speed of 6 knots, using the tactical diameter of turning circle D_t (Table 3 and Figure 8).

Table 3. Radius of turning circle R determination

Rudder angle	λ_1 [deg]	λ_2 [deg]	D_t [deg]	D_t [Mm]	R [m]
5°	14.2612	14.4426	0.1814	10.9	10079
10°	14.2612	14.3491	0.0879	5.3	4882
15°	14.2612	14.3242	0.0629	3.8	3497
20°	14.2612	14.3096	0.0483	2.9	2686
25°	14.2612	14.3004	0.0392	2.4	2177
30°	14.2612	14.2941	0.0329	2.0	1827
35°	14.2612	14.2898	0.0285	1.7	1586

The tactical diameter, D_t , and radius, R , of turning circle were calculated using the following formulas:

$$D_t = \lambda_2 - \lambda_1 \text{ [}^\circ\text{]} \quad (10)$$

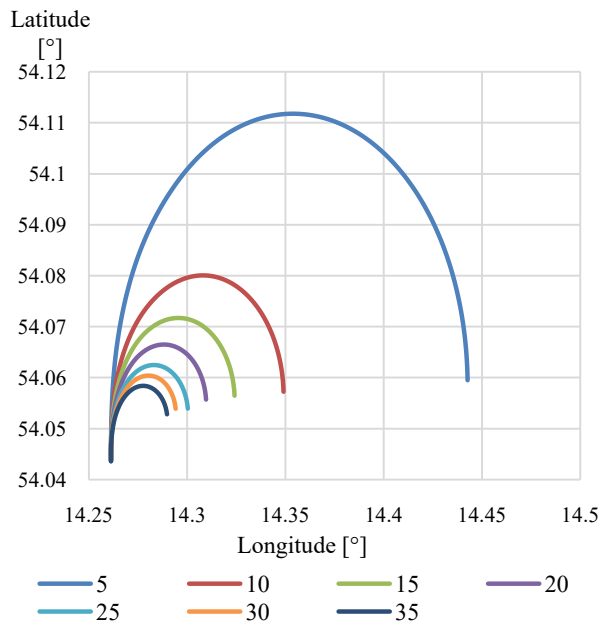


Figure 8. Diameter of tactical turning circle achieved from simulation passages of LNG Qflex with rudder angle interval from 5 to 35 deg

$$R = \frac{D_t}{2} \text{ [m]} \tag{11}$$

The vessel does not turn hard while entering the port; however, soft corrections of heading can cause the heel of such a large vessel.

The centrifugal force, F_z , appearing while the vessel turns, acts on the KG level and takes on the value of:

$$F_z = \frac{Mv^2}{R} \text{ [m]} \tag{12}$$

where:

M – mass of vessel with water that accompanies;

v – vessel speed while turning;

R – radius of turning circle

or, with the alternative method:

$$\tan \varphi = \frac{v^2 \cdot FG}{g \cdot R \cdot GM} \text{ [m]} \tag{13}$$

where:

FG – distance between vessel center of gravity and center of buoyancy (d_z parameter);

GM – intact metacentric height;

R – radius of turning circle.

In practice, the vessel heel is lower, because the contrary inclined rudder counterbalances its value (about 20%).

If we assume that the vessel makes minor corrections of heading using its rudder up to 10 deg (Table 4), the correction of vessel heel caused by its turning can be calculated with following formulas.

Heeling moment M_z :

$$M_z = F_z \cdot d_z \text{ [Tm]} \tag{14}$$

Determination of vessel heel φ :

$$\sin(\varphi) = \frac{M_z}{GM \cdot D} \tag{15}$$

Or, by an alternative method (Derret, 1999):

$$\tan \varphi = \frac{V^2 \cdot d_z}{R \cdot GM \cdot g} \text{ [m]} \tag{16}$$

Correction of vessel heel caused by its turning

$\Delta 7_z$:

$$\Delta 7_z = \frac{B \cdot \sin(\varphi)}{2} \tag{17}$$

Table 4. Correction of LNG Qflex vessel list caused by her turning

Rudder angle	del	deg	5	10	15	20	25	30	35
mass of vessel with water that accompanies	M	m^3	145200	145200	145200	145200	145200	145200	145200
turning circle radius	R	m	5979	2963	2167	1704	1648	1204	1065
start speed	V	m/s	3.3	3.3	3.3	3.3	3.3	3.3	3.3
centrifugal force	F_z	T	264.46	533.65	729.68	927.95	959.48	1313.3	1484.7
intact metacentric height	GM	m	5.3	5.3	5.3	5.3	5.3	5.3	5.3
vessel breadth	B	m	50	50	50	50	50	50	50
distance between vessel centre of gravity and centre of buoyancy	d_z	m	10.75	10.75	10.75	10.75	10.75	10.75	10.75
Heeling moment	M_z	Tm	2843	5737	7844	9975	10314	14118	15960
	$\sin(\varphi)$		0.00369	0.0074	0.0101	0.0129	0.0134	0.0183	0.0207
gravity	g	m/s^2	9.81	9.81	9.81	9.81	9.81	9.81	9.81
vessel heel	φ	deg	0.21	0.42	0.58	0.74	0.76	1.05	1.18
correction		m	0.09	0.18	0.25	0.32	0.33	0.45	0.51
	or:								
	$\tan(\varphi)$		0.00037	0.0007	0.0010	0.0013	0.0013	0.0018	0.0021
vessel heel	φ	deg	0.02	0.04	0.05	0.07	0.08	0.10	0.12
correction of vessel heel caused by her turning	$\Delta 7_z$	m	0.00	0.01	0.02	0.03	0.03	0.04	0.05

Vessel heel caused by tugs $\Delta 7_h$

In the calculations it has been assumed that the vessel heel is caused by thrust of two tugs (emergency situation), which pull the LNG Qflex in a 45 deg direction with respect to the vessel centerline.

Table 5. Vessel heel caused by tugs

U	200	T	tugs pull force
k	45	deg	towing line direction
F_h	141.42	T	lateral force made by tug
h_h	26	m	height of application of the tugs force measured from keel
d_{fh}	19.75	m	distance from point of application to center of buoyancy
M_h	2793.07	Tm	Heeling moment
$\sin(\varphi)$	0.0036		vessel heel
φ	0.21	deg	vessel heel
$\Delta 7_h$	0.09	m	correction of vessel heel caused by tugs

The following algorithm was used to determine the value of correction of vessel heel caused by tugs $\Delta 7_h$ (Table 5).

Value of lateral force made by tugs F_h :

$$F_h = \sin(k) \cdot U \quad [\text{T}] \quad (18)$$

Distance from point of application to center of buoyancy d_{fh} :

$$d_{fh} = h_h - \text{KF} \quad [\text{m}] \quad (19)$$

Heeling moment M_h :

$$M_h = F_h \cdot d_{fh} \quad [\text{Tm}] \quad (20)$$

Vessel heel caused by tugs:

$$\sin(\varphi) = \frac{M_h}{\text{GM} \cdot D} \quad (21)$$

Correction of vessel heel caused by tugs $\Delta 7_h$:

$$\Delta 7_h = \frac{B \cdot \sin(\varphi)}{2} \quad [\text{m}] \quad (22)$$

Summary of all corrections of LNG Qflex list – $\Delta 7$

The total correction of vessel list $\Delta 7$ can be defined as the sum value of all partial corrections:

$$\Delta 7 = \Delta 7_s + \Delta 7_w + \Delta 7_p + \Delta 7_z + \Delta 7_h \quad (23)$$

Conclusions

The paper describes methods of vessel draught, list and heel determination. The total correction of vessel list $\Delta 7$ for an LNG Q-flex type carrier was calculated considering the worst weather conditions that

still allow entrance to the outer port of Świnoujście and resulted in the value of 0.36 m. It is known that the experience of crew members has a direct impact on the amount of cargo that can be carried, as they know how to operate the deep draught vessel. The essence is that knowing the technological limits of equipment used to indicate the level of draught and list or heel is fundamental.

Basic calculations of vessel stability are very important to determine the draught, list and heel with the use of traditional methods. The following parameters have to be taken into consideration to calculate the value of total list, including heel components: draught readouts errors, influence of wind, current and tugboats, and heel caused by the vessel turning.

Systematic inspection and calibration of the modern measuring devices must be conducted to maintain a high accuracy of vessel draught, list and heel readouts. Additionally, to decrease the possibility of grounding, local regulations in the field of extra value of under keel clearance are implemented by ship owners. The additional UKC is expanded by so called “margin of safety”, added to the previously calculated UKC.

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Applications of global navigation satellite systems in maritime navigation

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Key words: GNSS, GPS system, GNSS receiver, shipborne GPS and GNSS receiver, type of GPS and GNSS receivers, maritime navigation

Abstract

Currently (April 2016) uninterrupted information about a ship's position can be obtained from specialized electronic position-fixing systems, in particular, Satellite Navigation Systems (SNSs) such as GPS and GLONASS and Satellite Based Augmentation Systems (SBASs) such as EGNOS or WAAS. The generic name given to all the above mentioned systems is Global Navigation Satellite Systems (GNSS). Many models, designed for the ship's bridge and provided by about a dozen manufacturers, are available on the world market. In Europe, one of the most comprehensive sources of knowledge on the global GNSS market is a report published, on average, every 15 months by the European GNSS Agency GSA. Another receiver survey is published each year in the January number of the magazine "GPS World". The detailed analysis of market report and receiver survey, possible use of EGNOS and Galileo in the maritime market, and different maritime applications of GNSS equipment are described in this paper.

Introduction

Uninterrupted information about a ship's position is one of the most important elements in the safety of navigation for sea transport in restricted and coastal areas, recommended by the International Maritime Organization – IMO. Currently (April 2016) information about the user's position is generally obtained from specialized electronic position – fixing systems. In particular, satellite navigation systems (SNS) such as the American GPS and Russian GLONASS systems; Satellite Based Augmentation Systems (SBAS), such as EGNOS in Europe, WAAS in USA and Canada, MSAS in Japan and GAGAN in India are employed (Januszewski, 2012; 2016; Betz, 2016; Glonass-IAC, 2016; GPS.GOV, 2016). All these systems are fully operational, next to SNS and Galileo in Europe, BeiDou in China, one SBAS and SDCM in Russia. Two regional navigation satellite systems (RNSS) – QZSS (Quasi Zenith Satellite System) in Japan and IRNSS (Indian Regional Navigation Satellite System) are also under construction.

The generic name given to all these systems is GNSS – Global Navigation Satellite System (Bei-Dou, 2016; Inside GNSS, 2016; GPS World, 2016).

At the time of writing (April 2016) more than 5 billion different GNSS devices are used around the globe. By 2023, this number is forecasted to increase to over 9 bln: more than one device per person. The primary region of global market is, and will be, the Asia-Pacific area, with a number of devices greater than EU and North America combined. The number of devices employed in EU28 and Non-EU28 European countries, in 2016, is about one billion (GNSS, 2015).

Maritime segment in GNSS Market Report

In Europe, one of the most comprehensive sources of knowledge and information on the dynamic, global GNSS market is a report published on average every 15 months by the European Global Navigation Satellite System Agency (GSA). In the first issue (October 2010) the number of GNSS market

Table 1. GNSS Market Report, cumulative core revenue (in %) in different market segments in different periods (GNSS, 2010; 2012; 2013; 2015)

Segment	Number of issue, month and year, number of pages			
	1, October 2010, 34	2, May 2012, 48	3, October 2013, 72	4, March 2015, 81
	Period			
	2010–2020	2010–2020	2013–2022	2013–2022
Location Based Service	42.8	43.7	47.0	53.2
Road	56.4	54.0	46.2	38.0
Surveying	–	0.6	4.1	4.5
Aviation	0.2	0.5	1.0	1.1
Maritime	–	0.1	0.3	1.1
Agriculture	0.6	1.0	1.4	1.9
Rail	–	–	0.1	0.2
Timing Synchronization	–	–	–	0.1

segments was equal to 4 (Location Based Service, Road, Aviation and Agriculture). In the latest (issue 4, March 2015) this number had increased to 8 (with the addition of Surveying, Maritime, Rail and Time Synchronization). The changes in the cumulative core revenue in each segment during the last years are presented in the Table 1.

Since the beginning of the reported period, the segment with the biggest revenue has been LBS (Location Based Service). Additionally, its value increases each year and in last issue it accounted for more than 50% of the cumulative revenue. The first mention about the application of these systems in the maritime segment appears in issue 2 (May 2012) when it accounted for only 0.1% of total core. This value increased in the last issue to 1.1%.

The market size of core revenues refers only to the value of GNSS receivers and chipsets in different devices, whereas enabled revenues include the full retail price of devices, smartphones in particular. The values of these two revenues, in Euros (EUR), were about 75 bln and 250 bln, respectively, in 2015. As both market sizes increase by few percentage points annually, we can expect that by 2023 these values will be about 110 bln and 300 bln, respectively.

Shipments of GNSS devices in Europe will more than double within the next 20 years, growing from 208 mln units in 2013 to 427 mln in 2023. Revenues will follow, increasing from 11 bln EUR in 2013 to 20 bln EUR in 2023. European companies account for one quarter of the global GNSS market and are the global leader (72%) in system integration in rail application as well as having a strong position in the maritime (47%) and road (29%) sectors. The group of companies classified into systems integrators comprises integrating GNSS capabilities into larger products, such as vehicles and consumer electronics, as well as dedicated (e.g. portable) GNSS devices.

In the maritime segment, GNSS is employed to satisfy the demand for navigation (in open areas at sea or in specific situations, such as harbor entrances and approaches) and positioning (including, among others, vessels monitoring, traffic management, locator beacons for distress situations, etc.) of vessels and crews by different stakeholders. That is why according to the distinction provided by IMO Resolution A.951(22) GNSS applications can be split into navigation and positioning:

- navigation
 - sea; SOLAS vessels: all passenger ships and cargo ships larger than 500 gross tons are regulated by and rely heavily on GNSS navigation; Non-SOLAS vessels: GNSS systems for maritime navigation are widespread across commercial and recreational vessels, both overseas and in high traffic areas;
 - inland waterways (IWW) as rivers, canals, lakes and estuaries: GNSS is also used to ensure safe navigation;
- positioning
 - traffic management and surveillance: these activities are supported by GNSS-based systems including AIS (Automatic Identification System) and LRIT (Long-Range Identification and Tracking);
 - search and rescue, different types of devices as EPIRBs (Emergency Position Indicating Radio Beacons), PLB (Personal Location Beacons), and AIS-SART (Search and Rescue Transmitter) can make use of GNSS;
 - fishing vessel control: GNSS positioning enables Vessel Monitoring Systems to check the position of fishing vessels;
 - port operations: Transit progress, docking and loading–unloading operations are monitored through GNSS-based technologies;

- marine engineering: GNSS is used to support marine construction activities.

The global number of vessels and ports in 2015 is shown in the Table 2. The recreational and merchant fleets are the most and least numerous, respectively, with about 29 mln and 81 thousand vessels each.

Table 2. Global number of vessels and ports in 2015 (GNSS, 2015)

Vessels				Ports	
Merchant	fishing	recrea- tional	inland waterways	sea port	recreational marinas
81,500	2.7 mln	29.2 mln	529,000	8,289	23,280 (20 countries)

Currently (2016) European GNSS (EGNSS) consists of two systems – EGNOS and Galileo. The possible uses of these systems in the maritime and other market segments for different applications are presented in the Table 3.

GNSS receivers on ships

In the case of maritime transport, almost all ships are equipped with one GPS/DGPS receiver at least. More frequently two receivers are present (either both of the same models or two units provided by different manufacturers), and sometimes three or four (special ships) devices are employed. The need to use the second SNS exists mainly in restricted areas where the position fix using one SNS only is impossible. On the ship, the user can determine its own position from other sources, e.g. the radar. That’s why at sea GNSS receivers (two or more SNSs) are still very rare (Januszewski, 2014).

The capability (in percentage) of GPS receivers integrated with at least one of the three SNS (GLONASS, Galileo and BeiDou) and/or at least one SBAS was shown for the first time in 2013, in issue 3 of GNSS Market Report. No information was available about manufacturers. In the last issue (No. 4), this survey contained information about the

31 manufacturers of more than 300 different GNSS receivers currently available on the market. All these GNSS receivers, chipsets and modules will be from now on called GNSS receivers (GNSS, 2013; 2015).

Another very well-known, and certainly also very comprehensive, receiver survey database for GPS and GNSS equipment is published annually in the January issue of the magazine “GPS World” (GPS World, 2016). In this survey we can find detailed information, i.e. 19 performance parameters, about several hundred receivers provided by several dozen manufacturers. In the number published in January 2016 the information was provided for 45 manufactures and more than 438 receivers. This receiver survey, based on performance parameter user environment and applications, distinguishes between 15 different types of users, one of which is marine (M). This type only was taken into account in the present paper. The total number of manufacturers and receivers designed for marine users in both surveys, GNSS Market Report and “GPS World”, are very similar, equal to 31 and 37, and 301 and 308, respectively.

Fifteen manufacturers (Furuno, Hemisphere GNSS, Japan Radio Co, Ltd, John Deere, Leica Geosystems AG, NavCom Technology, Inc., Nottingham Scientific Ltd, NovAtel, Rockwell Collins, Septentrio, SkyTraq Technology, Thales-Avionic Division, Topcon, Trimble and u-blox) are mentioned in the last survey of GNSS Market Report (issue 4) as well as in magazine “GPS World”. At least one of the GNSS receivers produced by these manufacturers is designed for the maritime segment, with the only exception of John Deere.

The percentage of GNSS integrated receivers (GPS system and/or SBAS or other SNS) in use in the different market segments in different years, reported in the two surveys, is presented in the Table 4. GNSS Market Report (issue 3, 2013) analysis was based on GPS World Survey 2013.

In the case of the maritime segment, the percentage use documented in the GNSS market report for the year 2015 is, for all three SNSs, greater than

Table 3. Possible use of European systems, EGNOS and Galileo, in maritime and other market segments for different applications (EGNOS, 2016; GNSS, 2015)

Applications	Market segments, maritime and	EGNOS	Galileo
Mass Market Consumer	LBS, road, aviation, rail	accuracy, especially in remote areas	availability, better resistance to multipath, accuracy, time to first fix
Liability-critical	LBS, road	integrity, accuracy	authentication, availability, accuracy, continuity
Safety-critical	LBS, road, aviation, rail	integrity, accuracy, compliance with safety requirements and standards	integrity, accuracy, compliance with safety requirements and standards, dedicated SAR service with return link

Table 4. Capability of GNSS integrated receivers (in percentage) according to GNSS Market Report (in all market segments and maritime segment) in different years and GPS World receiver survey (marine user) in 2016 (GNSS, 2013; 2015; GPS World, 2016)

GPS system and	GNSS Market Report				GPS World (marine user) 2016
	all market segments		maritime segment		
	2013	2015	2013	2015	
SBAS	74	62	89	77	91
GLONASS	48	55	46	68	77
Galileo	34	36	20	53	60
BeiDou	21	25	10	34	52
Number of the manufacturers	–	31	–	–	37
Number of GNSS receivers	–	300	–	–	308

the corresponding value for 2013 and, in comparison with all other market segments, lower in 2013 and higher in 2015. In the “GPS World” survey, the percentage of GNSS integrated receivers, relative to both SBASs and all SNSs, is greater than the value that appears in the GNSS Market Report for both all segments and the maritime segment only.

The surveys in GNSS Market Report and GPS World differ because the first takes into account four global SNSs, and in some cases SBAS only, while the second also accounts for two RNSS, QZSS and IRNSS.

Both in GNSS Market Report and “GPS World” Receiver Survey the analysis assesses the capabilities of receivers currently available on the market. That is why it is impossible to compare the distributions in separate years: each year different group of manufacturers are used in analysis.

The distribution of GNSS receivers (GPS only and multi-constellation), depending on the number of global SNS, in all 8 segments and in the maritime segment only, documented in the GNSS Market Report (issue 4) is presented in the Table 5. We can say that:

- distribution for all segments and maritime only differ; the percentage is highest in the case of the GPS-only and GNSS receivers of all four global SNSs respectively;
- the percentage for GNSS receivers of two SNSs is the biggest for GPS and GLONASS combination, both for all 8 segments and for maritime only.

In the survey of GNSS unit shipments by application we can distinguish 11 different types of application: Search & Rescue (PLB), Search & Rescue (EPIRB), Traffic Management, Homeland Security, Inland Waterway info, Ports, Marine Engineering, Fishing Vessels, Inland Waterway Navigation, Merchant Navigation and Recreational Navigation. The 4 types with the biggest number of the units are, and will be, Recreational Navigation, PLB and

Table 5. Distribution of GNSS receivers (in percentage) depending on the number of global satellite navigation systems in GNSS Market Report in all 8 segments and maritime segment only (GNSS, 2015)

Number of the systems	System	Per cent	
		all 8 segments	maritime segment
1	GPS only	41	24.5
2	GPS + GLONASS	22	22.0
	GPS + Galileo	4	5.0
	GPS + BeiDou	1	1.5
3	GPS + GLONASS + Galileo	8	12.5
	GPS + GLONASS + BeiDou	2	–
	GPS + Galileo + BeiDou	1	–
4	GPS + GLONASS + Galileo + BeiDou	21	34.5
Total (%)		100	100

EPIRB, and Merchant Navigation. Considering the geographical distribution of GNSS devices and revenues we can distinguish 6 regions: North America, EU28, Asia-Pacific, Non-EU28 Europe, Middle East + Africa, and South America + Caribbean. The regions with the biggest installed GNSS devices for maritime applications are the first three. North America is expected to remain the most important region, although Asia-Pacific is growing at a faster pace (GNSS, 2015).

GNSS Applications

The first applications planned for GNSS use were clearly military, and more precisely concerned the ability to provide a good departure location for inter-continental missiles launched at sea. Very soon after the military availability (1964) of the first SNS Transit (1967) the U.S. administration made the system available for civilian use also, and particularly for commercial maritime vessels. The main advantages of having an automatic positioning device are to

allow optimized routes over the oceans and also for increased security when facing bad weather.

GPS system has been available for civil and military use for more than two decades. Full Operational Capability of this system was declared in July 17, 1995 but in the early 90s GPS receivers could be already used in many different applications. That period of time has witnessed the creation of numerous new GPS applications. Because it provides high-accuracy positioning in a cost-effective manner, GPS has found its way into many industrial applications, e.g. marine applications, replacing conventional methods in most cases.

While not the largest market segment, marine navigation was the first to embrace satellite navigation. Today the market is maturing. Along with radios, AIS and radar, a GNSS receiver (in the most cases GPS receiver with or without DGPS or SBAS) is a piece of standard equipment on any ship or boat operating far from shore (Kaplan & Hegarty).

Typical maritime applications include rescue and replenishment of off-shore platforms, cruising positioning, digging waterways, or positioning and monitoring of off-shore platforms. Other typical applications consist in coupling GNSS receivers with dedicated sensors such as radar, ARPA, echo-sounder, fish-finders, and log. At sea, the receivers are usually quite crude as there is no possibility to implement techniques such as map matching, as one might be situated anywhere (Samama, 2008). A GNSS receiver can aid in the berthing and docking of large vessels, by means of position, attitude, and heading reference systems. These installations use multiple antennas aboard the vessel to determine an accurate representation of the ship's orientation. Combined with appropriate reference cartography, this can be an immense aid in the handling of large vessels in close quarters (Kaplan & Hegarty, 2006).

Marine seismic surveying is similar in principle to land seismic surveying. That is, a low-frequency acoustic energy is sent into the subsurface rock layers and is reflected back to the surface to reveal information about the composition of subsurface rocks. To obtain meaningful results, the position of the energy source and of the devices, called hydrophones, used for detecting reflected energy must be known with sufficient accuracy. This can be easily achieved, at lower costs, with GPS systems (El-Rabbany, 2002).

With the aim of differentiating and quantifying marine navigation safety requirements in the United States, the Federal Radionavigation Plan defined marine navigation in terms of phases

(Federal Radionavigation Plan, 2014). The four phases defined in this Plan are ocean, coastal, harbor/harbor approach (HHA), and inland water: each phase is characterized by a remarkably different set of performance requirements based on safety and environmental concerns and aimed at minimizing marine collisions, ramming, and grounding. The GNSS GPS system, in particular, is able to satisfy many of the ocean and coastal phase performance requirements. In exploiting GNSS, currently using GPS and DGPS, for the marine environment, particular attention has to be given to vessel footprint steering performance and the interplay between sensor and ship models. Other related functions, such as hazard warning, risk assessment, and on-line dynamics modelling, are also important elements (Prasad & Ruggieri, 2005).

According to (Hofmann-Wellenhof, Lichtenegger & Wasle, 2008) maritime navigation distinguishes between five major phases: ocean navigation, coastal navigation, port approach and operation in restricted waters, marine navigation in a port, and navigation in inland waterways. Satellite navigation provides a wide range of applications in the maritime domain. The position, velocity, and attitude determination capability of GNSS is used, e.g., in conjunction with river information service (RIS) to increase the situational awareness at inland waterways.

Maritime navigation is also one of the envisaged applications of the Galileo system, which is currently under construction. Open ocean and inland waterways are the most widely used modes for transporting goods worldwide, one of the strategic aims of the Galileo based transport network. Additionally, the high accuracy and integrity, certified services, and high availability brought by Galileo will be applied to leisure boats, commercial vessels, and all ships falling under the safety of life at sea convention in every phase of maritime navigation and in all weather conditions (Prasad & Ruggieri, 2005).

Conclusions

- GNSS navigation is being used in many different application areas, from purely commercial to highly scientific. In between, there are many professional domains that have found a great interest in using GNSS.
- Multi-constellation GNSS receivers became widely available on the world market, maritime market also.
- In the past few years, the GLONASS system has been the second system of choice after the GPS system.

- Detailed distribution of multi-constellation GNSS receivers consisting of a GPS receiver and one, two, three or four receivers of other systems showed that in each case the greatest percentage is when one of these systems is SBAS. This percentage will grow further with the expansion of SBAS coverage, particularly with new stations in the southern hemisphere.
- Galileo and BeiDou, two global satellite navigation systems under construction, are already present in several dozen per cent of multi-constellation receivers' models, well ahead of their full operational capability.

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Extreme value distributions in the analysis of traffic time on the Świnoujście–Szczecin fairway

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Key words: traffic time, fairway, generalized extreme value distributions, Frechet distribution, crossing time, simulated models

Abstract

The present article addresses the issue of crossing time on the fairway, modeling in restricted areas, where vessel traffic flow is disturbed. Data of movement time on the Świnoujście–Szczecin fairway was grouped according to ship type. The probability distributions describing the crossing time of different ship groups were analyzed. Using the Pearson chi-square goodness-of-fit and Cramer–von Mises tests it has been shown that the best distributions describing traffic time of all ship groups are the generalized extreme value distributions.

Introduction

To provide solutions to the many problems of marine traffic engineering, it is first necessary to know the probability distributions of particular random variables. This is very important, especially in simulated models (Gucma, Gućma & Zalewski, 2008). Recently, only certain standard distributions (e.g. normal, lognormal, uniform, exponential and Poisson) have been used for analysis of marine traffic (Kasyk, 2012).

The generalized extreme value distribution is a family of continuous probability distributions used in extreme value theory, especially in the economic and social sciences. Belonging to this family, among others, are: a Weibull distribution, a Gumbel distribution, an extreme value distribution and a Frechet distribution. Applications of Weibull distributions in different transport problems have been known for a long time (Gucma & Jankowski, 2001; Curbach, Gućma & Proske, 2005; Gućma, 2005; Smolarek, 2005). However, recently, distributions from this family have been used in the analysis of vessel traffic flows. The vessel speed in restricted areas, where a speed limit exists, may be described and modeled

by Gumbel distribution (Kasyk & Kijewska, 2014). The speed limit means that we deal with a distribution of extreme values. It is similar in the case of traffic time in restricted areas, where a speed limit exists.

The probability density function of the Weibull distribution is as follows:

$$f(x) = \frac{\lambda}{\beta} \exp\left(-\left(\frac{x-\alpha}{\beta}\right)^\lambda\right) \left(\frac{x-\alpha}{\beta}\right)^{\lambda-1} \quad (1)$$

The probability density function of the Gumbel distribution is as follows:

$$f(x) = \frac{\exp\left(\frac{x-\alpha}{\beta} - \exp\left(\frac{x-\alpha}{\beta}\right)\right)}{\beta} \quad (2)$$

The probability density function of the Frechet distribution is as follows:

$$f(x) = \frac{\lambda}{\beta} \exp\left(-\left(\frac{x-\alpha}{\beta}\right)^{-\lambda}\right) \left(\frac{x-\alpha}{\beta}\right)^{-1-\lambda} \quad (3)$$

The probability density function of the extreme value distribution is as follows:

$$f(x) = \frac{\exp\left(\frac{\alpha - x}{\beta} - \exp\left(\frac{\alpha - x}{\beta}\right)\right)}{\beta} \quad (4)$$

In all above formulas, α is a location parameter, β is a scale parameter and λ is a shape parameter.

Below, in Table 1, formulas for means and variances of the aforementioned distributions are presented.

Table 1. Means and variances of extreme value distributions

Distribution	Mean	Variance
Weibull	$\alpha + \beta \cdot \Gamma\left(1 + \frac{1}{\lambda}\right)$	$\beta^2 \left(\Gamma\left(1 + \frac{2}{\lambda}\right) - \Gamma\left(1 + \frac{1}{\lambda}\right)^2 \right)$
Gumbel	$\alpha - \gamma \cdot \beta$	$\pi^2 \beta^2 / 6$
Frechet	$\alpha + \beta \cdot \Gamma\left(1 - \frac{1}{\lambda}\right)$	$\beta^2 \left(\Gamma\left(1 - \frac{2}{\lambda}\right) - \Gamma\left(1 - \frac{1}{\lambda}\right)^2 \right)$
Extreme value distribution	$\alpha + \gamma \cdot \beta$	$\pi^2 \beta^2 / 6$

where:

γ – Euler’s constant, with numerical value ≈ 0.577216 ;

$\Gamma(z)$ – the Euler gamma function, which satisfies

$$\Gamma(z) = \int_0^\infty t^{z-1} e^{-t} dt.$$

The vessel traffic flow is not homogeneous. Different groups of ships have their own distributions. Consequently, in this article the data set of traffic time has been divided into seven groups, for the following types:

- barges,
- tankers,
- containers,
- cargo,
- general cargo,
- carriers,
- other ships.

For particular ship groups, a traffic time, from point Karsibor to point Dok5 in Szczecin harbor has been analyzed. Data from VTS Szczecin have been used. In hypothesis tests, a small p-value suggests that it is unlikely that the data came from the considered distribution (significance level is 0.05).

Distribution of traffic time on the Świnoujście–Szczecin fairway

The *Karsibor – Dok5* section is a part of the Świnoujście–Szczecin fairway, which is 53.7 km long. In the first half of 2009, in the north-south direction, 739 ships were registered on this section.

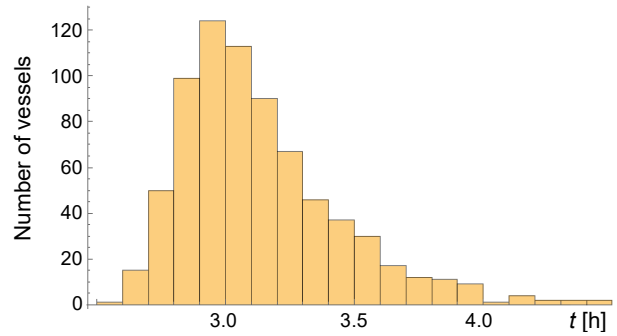


Figure 1. Histogram of traffic time on the Karsibor – Dok5 section

The minimal traffic time on this section is equal to 2.585 h, and the maximal traffic time is equal to 7.25 h. The mean time for all ships amounts to 3.16 h. And the standard deviation is equal to 0.41 h.

Table 2 presents the division of this set into seven groups.

Table 2. The number of different types of vessels on the Karsibor – Dok5 section

No.	Vessel type	Number of vessels
1.	Barges	27
2.	Tankers	67
3.	Containers	69
4.	Cargo	366
5.	General cargo	134
6.	Carriers	49
7.	Other ships	27

Traffic time distribution for barges

Figure 2 presents the frequency histogram and the graph of the probability density function of the extreme value distribution, fitted to data for barges.

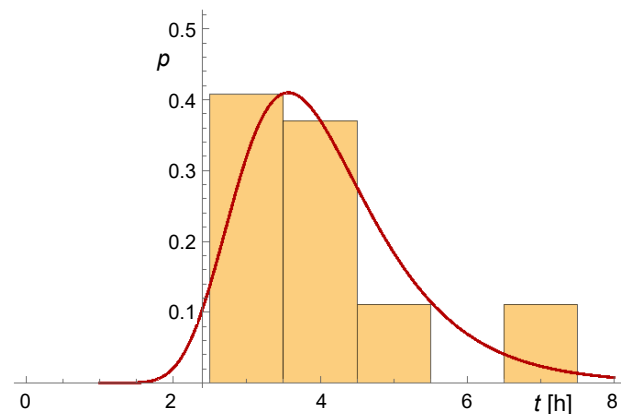


Figure 2. Frequency histogram of traffic time for barges

In the Pearson goodness-of-fit test chi-square test (Sobczyk, 2004; Rogowski, 2015) $p = 0.624$. In the

Cramér–von Mises goodness-of-fit test (Rogowski, 2015) $p = 0.805$. We are therefore unable to reject the hypothesis that the traffic time for barges between points 11 km and I Brama Torowa has an extreme value distribution. In this case, location parameter $\alpha = 3.566$ and scale parameter $\beta = 0.898$. The Empirical mean of data is equal to 4.078 h and theoretical mean from the extreme value distribution is equal to 4.084 h. Relative difference between these values is equal to 0.2%. Empirical variance of data is equal to 1.469 and theoretical variance from the extreme value distribution is equal to 1.326. Relative difference between these values is equal to 10%.

Traffic time distribution for tankers

Figure 3 presents the frequency histogram of data connected with tankers' traffic time.

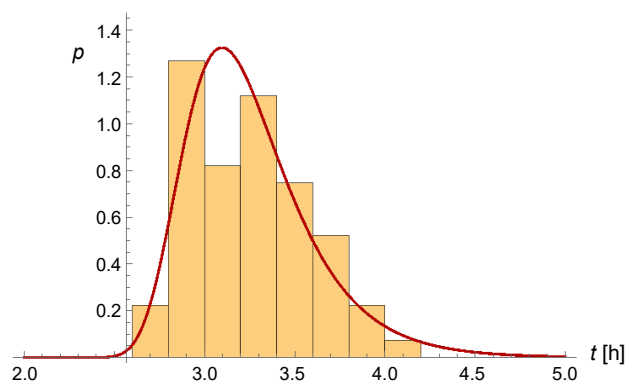


Figure 3. Frequency histogram of traffic time for tankers

Using the chi-square goodness-of-fit test we find that the $p = 0.47$. In the Cramér–von Mises goodness-of-fit test $p = 0.929$. So we can say that the traffic time for tankers has an extreme value distribution. In this case, location parameter $\alpha = 3.097$ and scale parameter $\beta = 0.277$.

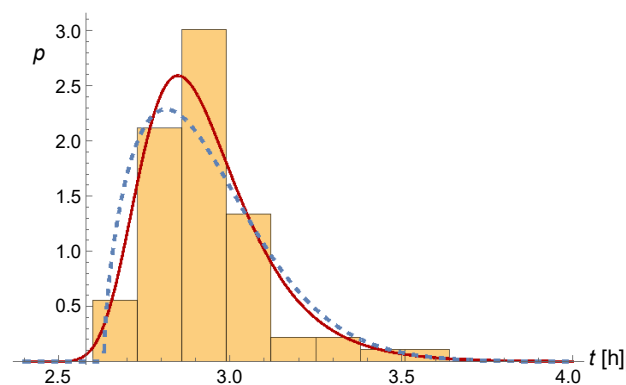


Figure 4. Frequency histogram of traffic time for containers

Traffic time distribution for containers

Figure 4 presents the histogram and the graph of extreme value distribution and Weibull (dashed) probability density function, fitted to data for containers.

The Pearson chi-square test and Cramér–von Mises test have shown that two distributions from the family of generalized extreme value distribution tests adequately describe the traffic time of containers between reporting points 11 km and I Brama Torowa. There are: the extreme value distribution with parameters $\alpha = 2.848$ and $\beta = 0.142$, and the Weibull distribution with parameters $\alpha = 2.633$, $\beta = 0.333$ and $\gamma = 1.602$.

Traffic time distribution for cargo ships

Based on the Pearson chi-square test and Cramér–von Mises test, we can accept that the extreme value distribution with parameters $\alpha = 3.0$ and $\beta = 0.23$, is well fitted to the data of traffic time for containers. Test probability $p = 0.09$ in the Pearson chi-square goodness-of-fit test and 0.33 in the Cramér–von Mises test.

Figure 5 presents the frequency histogram of data connected with cargo ship traffic time and probability density function of the fitted distribution.

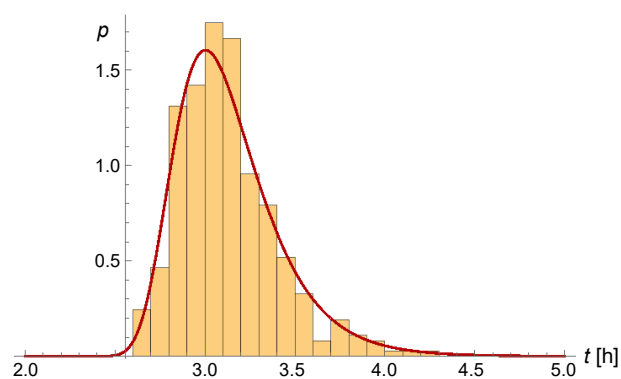


Figure 5. Frequency histogram of traffic time for cargo ships

Traffic time distribution for general cargo ships

Figure 6 presents the frequency histogram and the graph of extreme value distribution probability density function, applied to data for general cargo ships.

Using the chi-square goodness-of-fit test, we found $p = 0.43$. In the Cramér–von Mises goodness-of-fit test $p = 0.97$. Consequently, we are unable to reject the hypothesis that the traffic time of general cargo ships between reporting points 11 km and

I Brama Torowa has an extreme value distribution. In this case, location parameter $\alpha = 2.96$ and scale parameter $\beta = 0.219$.

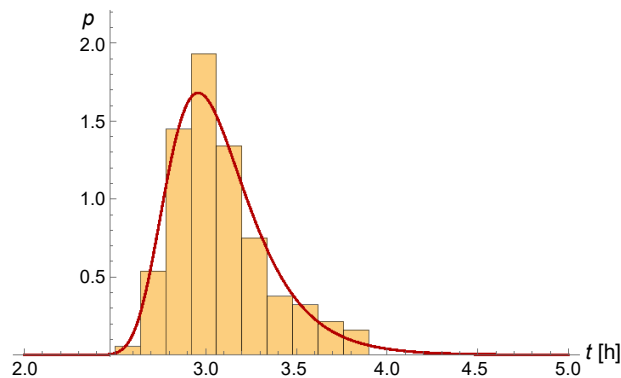


Figure 6. Frequency histogram of traffic time for general cargo ships

Traffic time distribution for carriers

Figure 7 presents the histogram and the graph of probability density function of distributions applied to data for carriers.

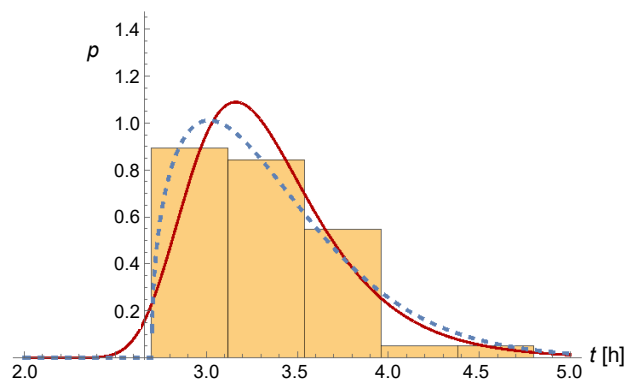


Figure 7. Frequency histogram of traffic time for carriers

On the basis of the Pearson chi-square test and Cramér–von Mises test, we can accept that the extreme value distribution with parameters $\alpha = 3.16$ and $\beta = 0.338$, and the Weibull distribution with parameters $\alpha = 2.7$, $\beta = 0.729$ and $\gamma = 1.429$ are well fitted to the data of traffic time for carriers.

Traffic time distribution for other ships

The group called “other ships” is comprised of: tugs, factory trawlers, research/survey vessels, suction dredgers, diving support vessels, ro-ro/passenger ships, fishing vessels and offshore supply ships.

Based on the Pearson chi-square test and Cramér–von Mises test, we can accept that the extreme value distribution with parameters $\alpha = 2.95$ and $\beta = 0.288$,

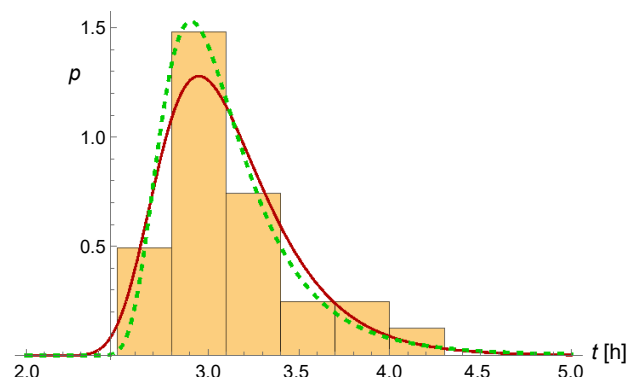


Figure 8. Frequency histogram of traffic time for other ships

and the Frechet distribution with parameters $\alpha = 1.09$, $\beta = 1.84$ and $\gamma = 7.59$ are well fitted to the data of traffic time for other ships.

Conclusions

All frequency histograms are asymmetric and all have negative coefficients of skewness. Different regulations (especially the speed limit) necessitate the use of extreme values in the analysis of vessel traffic flows. All presented vessel traffic time distributions are in accordance with an extreme value distribution. Furthermore, to some of them, a Weibull or a Frechet distribution fits well. Relative differences between empirical and theoretical means are less than 1%. Relative differences between empirical and theoretical variances are less than 20%. Using new distributions (especially Frechet) for the analysis of vessel traffic flows allows the building of better simulation models of vessel traffic. Two statistical goodness-of-fit tests have been used: the most universal and popular Pearson chi-square test, and the definitely stronger, but rarely used Cramér–von Mises test. Using the Cramér–von Mises test, we have a stronger basis for the application of verified distributions.

Acknowledgments

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Relevance of the relativistic effects in satellite navigation

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Key words: GPS, Galileo, GLONASS, BeiDou, COMPASS, IRNSS, satellite navigation, GNSS, relativistic effects, accuracy, clock offset, relativistic error

Abstract

Position determination of Global Navigation Satellite Systems (GNSS) depends on the stability and accuracy of the measured time. However, since satellite vehicles (SVs) travel at velocities significantly larger than the receivers and, more importantly, the electromagnetic impulses propagate through changing gravitational potentials, enormous errors stemming from relativity-based clock offsets would cause a position error of about 11 km to be accumulated after one day. Based on the premise of the constancy of light, two major relativistic effects are described: time dilation and gravitational-frequency shift. Following the individual interests of the author, formulas of both are scrupulously derived from general- and special-relativity theory principles; moreover, in the penultimate section, the equations are used to calculate the author's own numerical values of the studied parameters for various GNSSs and one Land Navigation Satellite System (LNSS).

Introduction

The twentieth century brought the first precise global satellite navigation systems. In 1964, the pioneer TRANSIT was launched, accompanied 10 years later by a nemesis system, Cykada. Both of these were ultimately replaced by their more advanced counterparts and several other satellite systems were installed (Specht, 2007). Today, four major systems can be listed, namely GPS, Galileo, GLONASS, and Chinese BeiDou, though the last is currently under further development (conversion from local BeiDou to global COMPASS). The fact that the Indian Regional Navigation Satellite System (IRNSS) is a local satellite system notwithstanding, it will also be taken into consideration in the final part of this paper. The common factor of all these positioning systems is in terms of precision (Specht, 2003; Januszewski, 2005). Nonetheless, each and every SV's clock is prone to gravitational and motional frequency shifts that are too significant to ignore (Narkiewicz, 2007). If a clock is provided with unsupported time determination due to numerous relativistic effects, then, based on the special and general theory of relativity,

the system should be rendered non-operational. In this paper, ways of calculating such effects are undertaken and an example is shown, focusing on the very derivation of error-figuring formulas. This is done in hope that when relativistic effects are fully understood, diminishing them to an insignificant size should be possible.

Principles of satellite systems

The principles of position determination in satellite systems are based on constancy of the speed of electromagnetic signals. It can be accomplished, provided that both the user of the GNSS and the satellite itself have their clocks synchronized in one mutual, underlying, inertial frame (Januszewski, 2010). The signals sent to the receiver are provided with an encrypted message (Specht, 2007). Within the message, the information about the time and position of the constellation is coded. By comparing the time of the SV and receiver, the distance is calculated (Januszewski, 2004). Mathematically it can be stated as follows:

$$d = c (t_0 - t_{sv}) \quad (1)$$

Figure 1 illustrates how this is performed in the GPS. In order to determine the position unambiguously, at least four time signals need to be received, so four equations (1) are solved to provide the position (Narkiewicz, 1999; 2007).

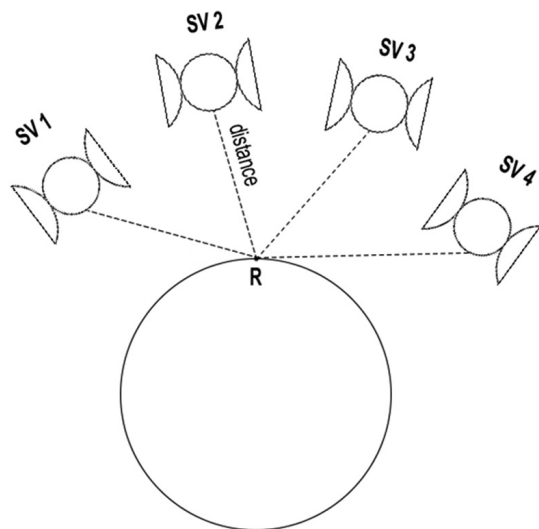


Figure 1. The distance in satellite navigation is calculated as the speed of light multiplied by the time difference

Since the only navigational parameter that is used for calculations is the time, it is convenient to measure the error in seconds (Narkiewicz, 1999; 2007); for instance, an error of 1 nanosecond would cause a position error of about 30 centimeters.

Principles of relativity

The special (1905) and general (1915) theory of relativity published by Albert Einstein have fundamentally changed people's understanding of the nature. Contrary to the Newtonian framework of absolute space and time, three postulates of the summed theories of relativity may be stated (Williams, 1968):

- (1) The laws of physics have the same form in all inertial and non-inertial reference frames.
- (2) The speed of light c (299,792.46 km/s) in a vacuum is a constant and does not depend on the motion of the source.
- (3) Occurrences due to a gravitational mass are indistinguishable from occurrences due to an inertial mass.

Time dilation

One of the relativity-based errors is caused by the time dilation between the satellites' and the receiver's clocks. That means the moving clocks beat

slower than clocks that are stationary (Narkiewicz, 2007). The effect stems from a Lorentz transformation that applies to inertial reference frames (Williams, 1968). Most trivial derivations of the formula for time dilation are as follows: imagine a vehicle moving at velocity V . A flashlight is inserted on the floor of the considered vehicle and a single light impulse is emitted towards a mirror set on the very opposite of the torch, onto the ceiling. The impulse is hence reflected and the time of the operation is recorded. There are two particular observers of the ongoing action: one bound with the frame of the vehicle (inside) and the other outside and stationary. The situation is pictured in the Figure 2.

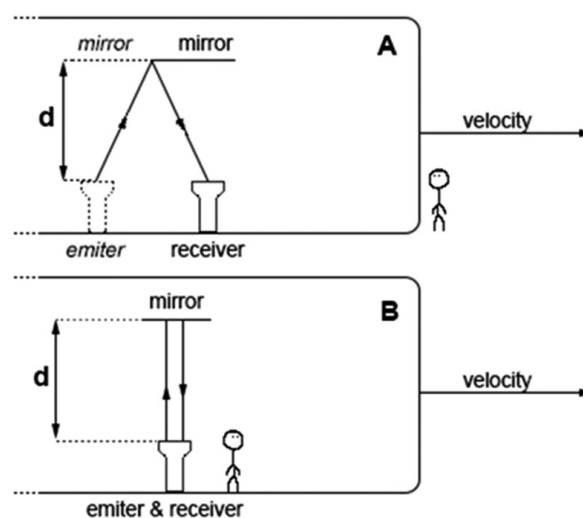


Figure 2. Situation A shows how the route of the flash impulse is seen by a keen observer not bound with the inertial frame of the vehicle. Contrastingly, situation B shows the light pulse as observed within the frame

The point is that although the same event is observed by both people, different routes of the light impulse are perceived. For both situations, a simple equation can be written. For situation A, it is:

$$c = \frac{\sqrt{4d^2 + (vt_B)^2}}{t_B} \quad (2)$$

and for situation B:

$$c = \frac{2d}{t_A} \quad (3)$$

Equations (2) and (3) can be further expressed as follows:

$$t_B = \frac{2d}{c} \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (4)$$

$$t_A = \frac{2d}{c} \quad (5)$$

From both (4) and (5), the final formula for time dilation in Lorentz transformation is derived:

$$t_B = t_A \sqrt{1 - \frac{v^2}{c^2}} \quad (6)$$

$$\delta_{\text{time dilation}} = \frac{t_B - t_A}{t_A} \quad (7)$$

This formula states the size of the error based on the time-dilation process. Specifically, it shows that for every piece of time that flows on Earth a change of:

$$\delta_{\text{time dilation}} = \sqrt{1 - \frac{v^2}{c^2}} - 1 \quad (8)$$

occurs on the orbit of the SV. That means that a clock there is slower than a clock on the surface. The new-born error must be naturally compensated in order to maintain the agreement between the clocks and to secure the precise position determination.

To finalize this error analysis, the velocity of the satellite vehicle is to be calculated and inserted into formula (8). From Kepler's Third Law, the period of revolution in Earth's gravitational field can be calculated as (Williams, 1968):

$$T^2 = \frac{4\pi^2 e^3}{Gm_E} \quad (9)$$

where $G = 6.6740831 \cdot 10^{-11} \text{ m}^3/\text{kg} \cdot \text{s}^2$ is the gravitational constant, $m_E = 5.9722 \cdot 10^{24} \text{ kg}$ is the mass of Earth, e is the semi-major axis of concrete SV, and T is its period of revolution. From that, the period of revolution is used to determine the orbital speed of a SV:

$$v = \frac{2\pi e}{T} \quad (10)$$

Substituting $e = 2.65594 \cdot 10^7 \text{ m}$ (for GPS satellites), it is found that $T = 43,077 \text{ s}$. Consequently, the velocity is $3,873.95 \text{ m/s}$. Finally, the clock error due to time dilation is calculated as following:

$$\delta_{\text{GPS time dilation}} = \sqrt{1 - \frac{v^2}{c^2}} - 1 = -8.34903 \cdot 10^{-11} \quad (11)$$

To calculate this offset for a particular time, it needs to be integrated:

$$\tau = \int_{\text{time}} \delta_{\text{time dilation}} dt = \int_{\text{time}} \left(\sqrt{1 - \frac{v^2}{c^2}} - 1 \right) dt \quad (12)$$

For instance, this effect after one day (86,400 seconds) causes a clock offset of about $7.21 \mu\text{s}$, which therefore would result in an astonishingly large error of 2,163 meters.

Gravitational frequency shift

Somewhat more complex is the problem of light travel through space-time. The gravitational field is conservative and stems from the pure mass of inducing the object (Williams, 1968). In 1687, Sir Isaac Newton articulated his Law of Gravitation, which is as follows: "Every particle of matter in the universe attracts every other particle with a force that is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them".

Mathematically, this is expressed with:

$$\vec{\mathbf{F}}_{\text{gravitation}} = \frac{Gm_1m_2}{r^3} \vec{\mathbf{r}} \quad (13)$$

where r is the distance between two particular masses m_1 and m_2 . More importantly to the studied case, it can be also stated as:

$$\vec{\mathbf{F}}_{\text{gravitation}} = -\nabla \cdot U_{\text{gravitation}} \quad (14)$$

which means the gravitational force is the negative gradient of the gravitational potential energy (Williams, 1968). Further, the potential energy can be calculated as the gravitational potential multiplied by the elementary mass:

$$U_{\text{gravitation}} = \Phi_g m \quad (15)$$

Earth may be considered a perfect sphere in regards to an induced gravitational field, to a good approximation. Thus, the gravitational interactions involving such a spherical body can be treated as if all the mass was concentrated at the center of the object. That said, it is easy to derive the formula for gravitational potential energy within Earth's field (by integrating (13) over distance):

$$U_{\text{gravitation}} = -\frac{GM_E m}{r} \quad (16)$$

In order to understand errors in satellite navigation positioning caused by gravitational frequency shift, consider a particle of light (an electromagnetic impulse) that is emitted at point A and received at point B (Figure 3). Upon travelling the described distance, the signal leaves a quasi-potential surface of energy, amounted to:

$$U_A = -\frac{GM_E m}{r_A} \quad (17)$$

and enters a significantly stronger field of:

$$U_B = -\frac{GM_E m}{r_B} \quad (18)$$

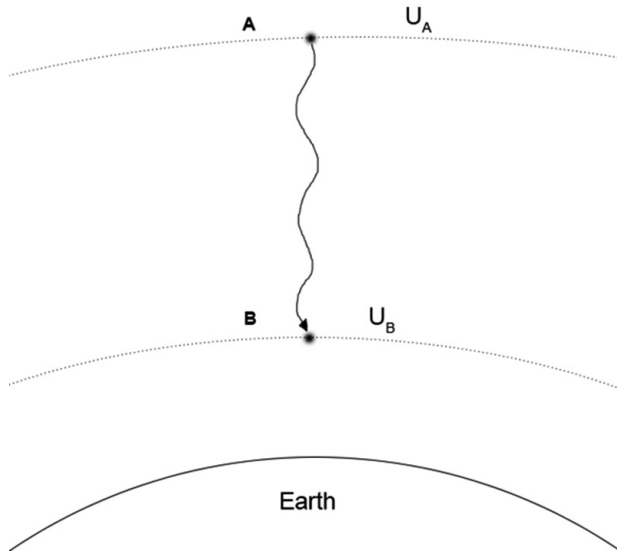


Figure 3. The change of gravitational potential energy as an object approaches the Earth's center of mass

The electromagnetic wave (photon) itself has an energy proportional to its frequency (Williams, 1968), by:

$$E = h \nu \quad (19)$$

and, on the other hand, its energy is described by Einstein's best known equation:

$$E = m c^2 \quad (20)$$

Since there is conservation of energy, the overall energy must be stated as a constant function of distance from the mass inducing the gravitational field. That means that the overall energy of a signal at point A must precisely equal the energy at point B:

$$E_A = E_B \quad (21)$$

Yet there is a significant change in the gravitational potential energy:

$$\Delta U = U_A - U_B \quad (22)$$

$$\Delta U = \Delta \Phi_g m \quad (23)$$

Having that formulated, it is now possible to compare the energy of the impulse from positions A and B. In order to maintain the same amount of energy, the frequency of the electromagnetic wave changes, thereby compensating for the deficit of gravitational potential energy. By comparing the energy at point A and B, the exact gravitational frequency shift can be derived:

$$h \nu_A = h \nu_B + \Delta \Phi_g m \quad (24)$$

Putting:

$$m = -\frac{h \nu_A}{c^2} \quad (25)$$

in (24) for m will result in:

$$h \nu_A = h \nu_B - \Delta \Phi_g \cdot \frac{h \nu_A}{c^2} \quad (26)$$

and eventually:

$$\frac{\nu_B}{\nu_A} - 1 = \frac{\Delta \Phi_g}{c^2} \quad (27)$$

$$\frac{\Delta \nu}{\nu} = \frac{\Delta \Phi_g}{c^2} \quad (28)$$

Hence, with the change of the gravitational field, the received frequency of the light signal changes according to (28). This phenomenon is recognized within the general theory of relativity and is referred to as gravitational frequency shift or gravitational redshift.

This model was labeled as one with good approximation but for the purposes of this study a deeper insight is needed, as far as Earth's gravitational field is concerned. Equation (16) shows, for an ideally-spherical body, the distribution of gravitational potential as a function of only distance from the center of the mass. Adding to this the fact that Earth is a geoid of a complex structure, the equation would be:

$$\Phi(r, \theta) = -G \frac{M_E}{r} \left[1 - J \left(\frac{R_E}{r} \right)^2 P_2(\cos \theta) \right] \quad (29)$$

where: r is the distance from the center of the Earth's mass, θ is the polar angle measured downward from the axis of rotational symmetry, J is earth's quadrupole moment coefficient, and P_2 is the Legendre polynomial of degree 2, which stands for:

$$P_2(\cos \theta) = \frac{1}{2} (3 \cos^2 \theta - 1) \quad (30)$$

On the whole, the time rate is lower in a more intense gravity field; hence on the surface of Earth, a clock will run slower than on the orbit of the SV. Since the formula has been derived, the real error of this kind may be calculated. To calculate it, only the height (altitude) of the satellite is needed, as it is the only variable contributing to the change of gravitational field. Using $H = 20,162$ km, $\theta = 90^\circ - 55^\circ$ (as for GPS SV), $J = 1.08263 \cdot 10^{-3}$, and $R_E = 6378.14$ km, the error is found to be:

$$\delta_{\text{GPS redshif}} = \frac{\Phi_g(R_E + H) - \Phi_g(R_E)}{c^2} \quad (31)$$

$$\delta_{\text{GPS redshif}} = 5.2835 \cdot 10^{-10} \quad (32)$$

Similarly to (12), in order to gain a numerical value of a one-day offset, (32) needs to be integrated over time:

$$\begin{aligned}\tau &= \int_{\text{time}} \delta_{\text{GPS redshift}} dt = \\ &= \int_{\text{time}} \left(\frac{\Phi_g(R_E + H) - \Phi_g(R_E)}{c^2} \right) dt \quad (33)\end{aligned}$$

Comparing this effect to the time dilation after one day (86,400 seconds), it causes a clock offset of about 45.65 μs , which therefore would result in an even larger error of 13,685.53 meters.

Overall offset and other effects

It is important to emphasize that, interestingly, the relative-error effects derived from time dilation and gravitational frequency shift have opposite signs and are diminishing themselves (Narkiewicz, 1999; 2007). That is to say that a detailed calculation may prove that at the height of about 6,000 km, the effects would counteract each other (Narkiewicz, 2007). That fact notwithstanding, the overall relativistic effect in a satellite navigational system can be calculated from an integral, which is a combination of (12) and (33):

$$\begin{aligned}\tau_o &= \int_{\text{time}} (\delta_{\text{redshift}} + \delta_{\text{time dilation}}) dt = \\ &= \int_{\text{time}} \left(\frac{\Phi_g(R_E + H) - \Phi_g(R_E)}{c^2} + \sqrt{1 - \frac{v^2}{c^2}} - 1 \right) dt \quad (34)\end{aligned}$$

For GPS satellites, the overall error is calculated as 38.44 $\mu\text{s/day}$ or $\Delta f/f = 4.4486 \cdot 10^{-10}$. Since this clock offset tends to decrease the quality of service

and is omnipresent, GPS frequency is modified in a way that the frequency of satellite vehicles of Global Positioning System on Earth would be measured as:

$$\begin{aligned}10.23 \text{ MHz} - 10.23 \text{ MHz} \cdot 4.4486 \cdot 10^{-10} &= \\ = 10.2299999954491 \text{ MHz} \quad (35)\end{aligned}$$

Thanks to this effect, a receiver on Earth is capable of receiving a standard frequency of 10.23 MHz. The value of the change calculated in (35) is nearly equal to the one stated by Narkiewicz (2007). It is possible to calculate that daily clocks on SVs are slowed by $4.4486 \cdot 10^{-10} \cdot 86,400 \text{ s} = 38.436 \mu\text{s}$. The greatest part of the relativity-based error is thus removed and compensated, albeit other types of errors are still present, nonetheless of lesser significance. These are Sagnac effects and the periodic tidal effect of the Moon and Sun. But then again, they are removed by way of signal processing in the receiver using following equations:

$$t = t_{SV} - \Delta t_{SV} \quad (36)$$

$$\Delta t_{SV} = A_0 + A_1 (t - t_0) + A_2 (t - t_0)^2 \quad (37)$$

where: A_0 , A_1 , and A_2 are coefficients of the provided polynomial and are directly transferred via the GPS message, and t_0 is the referent time. Ultimately, there is the eccentricity-effect correction, which is mathematically specified with the formula:

$$\Delta t_{SV} = Fe\sqrt{a} \cdot \sin E \quad (38)$$

where: F , e , and E are parameters of the satellite and are also taken from the GPS message, while F is a system constant = $4.442807 \cdot 10^{-10} \text{ s} \cdot \text{m}^{-0.5}$.

Table 1. Satellite parameters and corresponding to them relativistic effects for major GNSSs (Dana, 1995; FindTheData, 2016; GSC, 2016; IAC, 2016; ILRS, 2016; N2YO, 2016; PosiTim, 2010; SatelliteCoverage, 2016; Spaceflight Insider, 2015)

Factor	GPS	GLONASS	Galileo	Beidou Compass	IRNSS
Satellite's name / number	GPS IIF	13	Galileo-101	COMPASS-M3	IRNSS-1A
Orbit	MEO	MEO	MEO	MEO	GEO
Semi-Major axis [km]	26559.4	25508	29599.8	21528	42164
Altitude [km]	20183.5	19132	23014.5	21527.5	35786
Perigee [km]	19652	18622	23013	21460	35707
Apogee [km]	20715	19642	23016	21595	35884.7
Eccentricity	0.002	0.00085	0.001	0.0025	0.0002
Inclination [rad]	0.95	1.13	0.97	0.95	0.51
Period of revolution [s]	43077.6	40543.9	50688	46403.4	86172
Average velocity [m/s]	3873.95	3669.598826	3952.981413	3779.324488	3074.624434
Relativistic effect	GPS	GLONASS	Galileo	Beidou Compass	IRNSS
Frequency change of time dilation $\Delta f/f$ [s/s]	-8.34903E-11	-7.49145E-11	-8.69317E-11	-7.94615E-11	-5.25912E-11
Time dilation [μs per day]	-7.21	-6.47	-7.51	-6.86	-4.54
Gravitational frequency change $\Delta f/f$ [s/s]	5.28355E-10	5.21454E-10	5.44268E-10	5.36396E-10	5.90633E-10
Gravitational redshift [μs per day]	45.65	45.05	47.02	46.34	51.03
Total relativistic offset [μs per day]	38.44	38.58	39.51	39.48	46.49
Total relativistic offset [km per day]	11.52	11.56	11.84	11.83	13.94

Numerical data

Using formulas derived in previous sections of this paper, the specific, relativistic clock offsets were calculated by the author. It is also important to note that each error and its value is strictly individual and depends on the characteristics of a particular SV's orbit. In the Table 1 most basic and significant parameters of different satellite systems are collected, as well as time-dilation error and gravitational-frequency shift error are calculated for those GNSSs using data published by authorized sources for particular SVs. All constants used in calculations are those used and stated previously; that also applies to the formulas themselves.

Conclusions

In order to maintain precise positioning, the relativistic effects need to be taken into consideration and thoroughly calculated. All of the currently-used, global-navigation satellite systems base their working schema on the concept of clock synchronization to receivers within Earth's inertial reference frame. However, since their value stems from each orbit's constellation numerical parameters, relativistic errors of different GNSS have comparable values. Nonetheless, clocks' offsets are too significant to be ignored and ways of reducing them are presented, thus making diminishment of the error forced by the very forces of gravitation possible.

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Dynamic optimisation of safe ship trajectory with neural representation of encountered ships

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Key words: marine transport, safe navigation, optimisation, artificial intelligence, computer simulation, decision support systems

Abstract

This paper describes an application of the dynamic programming method to determine the safety of one's own ship trajectory during encounter of other ships. A dynamic model of the process, with kinematic constraints of state and determined by a three-layer artificial neural network has been used for the development of control procedures. Non-linear activation functions in the first and second layers may be characterised by a tangent curve while the output layer is of a sigmoidal nature. The Neural Network Toolbox of the Matlab software has been used to model the network. The learning process used an algorithm of backward propagation of the error with an adaptively selected learning step. The considerations have been illustrated through an example implemented in a computer simulation using the algorithm for the determination of the safe ship trajectory in situations of encounter of multiple ships, recorded on the ship's radar screen in real navigational situation in the Kattegat Strait.

Introduction

Safe ship navigation is one of the most important problems in marine navigation. It is difficult to make correct decisions during a collision situation because of the growing size, velocity and number of ships that are taking part in maritime transport. At the same time, there is a tendency in the domain of ship control towards automation of processes for choosing optimal manoeuvres or safe trajectories based on the information from the anti-collision system ARPA (Automatic Radar Plotting Aids). The ARPA system enables to automatically track at least $j = 20$ ships encountered, to determine their movement parameters (speed V_j and course ψ_j) and elements indicating their closing to one's own ship (D_{CPA_j} – Distance of the Closest Point of Approach and T_{CPA_j} – Time to the Closest Point of Approach) together with the risk of collision, r_j ; however, the operational range of a standard ARPA system ends up with the simulation of a manoeuvre selected by navigator (Bist, 2000; Kouemou, 2009).

Multistage safe ship control

Safe ship control depends on continuing observation of the situation at sea, determination and realisation of the anti-collision manoeuvre, and safe travel to the destination point. It is therefore important to determine the safe trajectory of a ship as sequence of single manoeuvres, and course and/or speed as a multistage decision-making process (Wiśniewski, 2011).

The problem of the development of the multistage control process is very difficult, considering the high complexity of steering, which has dynamic, non-linear, multi-dimensional, non-stationary and game controlling features. In practice, the methods for the selection of a manoeuvre or trajectory assume the form of relevant controlling algorithms, programmed in the microprocessor controller generating the option of the ARPA anti-collision system or of the training simulator (Cross, 1994; Modarres, 2006).

The steering mode of a ship depends on the range of precision of the information on the current

navigational situation and on the adopted model of the process. During the development of the process the following relevant elements are to be considered: equations of kinematics and dynamics of the ship, disturbances generated by the sea's wave motion as well as wind and sea currents, navigational constraints, strategy of the encountered objects and the purpose of the control. A wide variety of models directly influence the synthesis of various algorithms of control and the effects of safe steering (Leondes, 1998).

Model of control process

A ship's steering under collision situations may be characterised by high alterations of the course, within the range $20^\circ-90^\circ$, and reduction of speed by not more than 30%. The model of the ship's dynamics may be presented as in Figure 1.

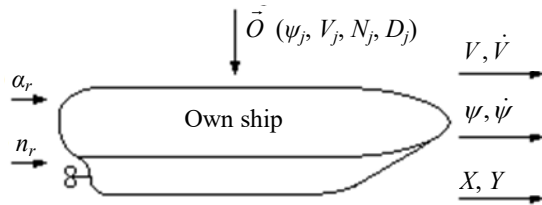


Figure 1. Ship as object of control: α_r – reference rudder angle, n_r – reference rotational speed of screw propeller, ψ – course, $\dot{\psi}$ – turning speed, V – speed, \dot{V} – acceleration, (X,Y) – position, \bar{O} – constraints as encountered j ship: ψ_j – course, V_j – speed, N_j – bearing, D_j – distance

The simplifications introduced in the model of the ship's dynamics include the omission of the drift angle and fall in the ship's speed during the manoeuvre, the adoption of a non-linear mathematical description of the ship's dynamic features in the rudder control system according to Nomoto, and a linear model for the control system of the rotational speed of the propeller.

State process equations

The description of the ship's dynamics can be represented by the following state equations:

$$\left. \begin{aligned} x_{1,k+1} &= x_{1,k} + x_{5,k} \cdot \Delta t_{k+1} \cdot \sin x_{3,k} \\ x_{2,k+1} &= x_{1,k} + x_{5,k} \cdot \Delta t_{k+1} \cdot \cos x_{3,k} \\ x_{3,k+1} &= x_{3,k} + x_{4,k} \cdot \Delta t_{k+1} \\ x_{4,k+1} &= x_{4,k} + \frac{1}{T_1} (-x_{4,k} - a_1 \cdot x_{4,k} |x_{4,k}| + \\ &\quad + k_1 \alpha_{\max} \cdot u_{1,k}) \Delta t_{k+1} \end{aligned} \right\} \quad (1a)$$

$$\left. \begin{aligned} x_{5,k+1} &= x_{5,k} + x_{6,k} \cdot \Delta t_{k+1} \\ x_{6,k+1} &= x_{6,k} + \frac{1}{T_2 T_3} [-(T_2 + T_3)x_{6,k} - x_{5,k} + \\ &\quad + k_2 \cdot n_{\max} \cdot u_{2,k}] \Delta t_{k+1} \\ x_{7,k+1} &= x_{7,k} + \Delta t_{k+1} \end{aligned} \right\} \quad (1b)$$

where $x_1 = X$; $x_2 = Y$; $x_3 = \psi$; $x_4 = \dot{\psi}_{\max}$; $x_5 = V$; $x_6 = \dot{V}$; $x_7 = t$; $u_1 = \alpha_r / \alpha_{\max}$; $u_2 = n_r / n_{\max}$; a_1, k_1, k_2 – gain coefficients; T_1, T_2, T_3 are time constants.

The identification research conducted with regards to a few types of cargo vessels under regular operational conditions at various speeds and loading states allows for the following assessment of the values of the parameters present in the above model: $T_1 = 5 \div 50$ s, $T_2 = 10 \div 100$ s, $T_3 = 50 \div 500$ s, $a_1 = 50 \div 1000$ s/rad, $k_1 = 0.01 \div 0.3$ 1/s, $k_2 = 1 \div 10$ m.

Control and state constraints

The constraints of control and the state of the process are a result of the necessity to consider the physical values characterising the process:

$$u_1 \leq 1, \quad 0 \leq u_2 \leq 1 \quad (2)$$

$$0 \leq x_4 \leq \dot{\psi}_{\max}, \quad 0 \leq x_5 \leq V_{\max}, \quad 0 \leq x_6 \leq \dot{V}_{\max} \quad (3)$$

and the consideration of real navigational constraints:

$$g_n(x_1, x_2) \leq 0 \quad (4)$$

At the same time, to ensure safe shipping it is necessary to consider the recommendations of the international regulations on the priority way, COLREG (Collision Regulations). In accordance with regulation 17, and in conditions of good visibility at sea, the way of the vessel approaching from the right subsists:

$$g_j(\psi_j, V_j, N_j, D_j) \leq 0 \quad (5)$$

Control quality index

The basic quality index the ship's control is to ensure safe passing of the encountered ships, which is considered in the state constraints of Eq. (5). Moreover, a goal function for optimisation is taken into consideration in the form of the smallest possible way loss required for safe passing of the encountered ships, which, for a constant speed of one's own ship, leads to the time-optimal control:

$$I(u_1, u_2) = \int_0^{t_k} x_5 dt \cong x_5 \int_0^{t_k} dt \rightarrow \min \quad (6)$$

Neural representation of encountered ships

Ships domains

The areas in which the risk of collision exists, known as the *encountered ships domains*, are created in the *neural constraints* computer programme procedure (Colley, Curtis & Stockel, 1983; Dovie, Dove & Stockel, 1980). The adopted ships' domains are represented as a circle, in conditions of restricted visibility, and, in conditions of good visibility, in the form of a circle for ships on the left side and of a parabola, ellipse, or hexagon, for ships on the right side. The dimensions of domains depends on the relative speed of the ship being passed and are modified on the basis of the answer from an appropriately prepared neural network which assesses the degree of the collision risk (Figure 2).

One of the fundamental factors to be taken into consideration when the ship's domain is determined is the safe distance, D_s . This is the smallest acceptable distance between the ship and the navigational obstacle. This parameter is estimated by the navigator based on the current navigational situation and is usually equal to the D_{CPA_j} distance (0.5–3.0 Nm) (Goodvin, 1975).

For a comparative analysis, different domain shapes are assumed. The circle domain (5) is formulated as a circle with radius equal to D_s :

$$g_j^c(X_j, Y_j) = X_j^2 + Y_j^2 - D_s^2 \leq 0 \quad (7)$$

where (X_j, Y_j) are the co-ordinates of the j -th encountered ship.

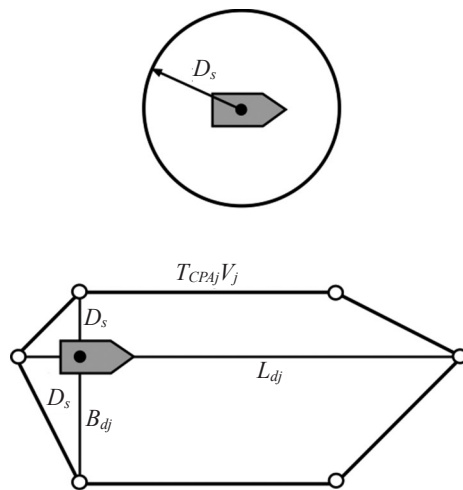


Figure 2. Shapes of domains of neural encountered ships

The parabolic form of constraint (5) is described by the equation:

$$g_j^p(X_j, Y_j) = X_j \sin \psi_j + Y_j \cos \psi_j + \\ -\zeta (X_j \cos \psi_j - Y_j \sin \psi_j - D_s)^2 \leq 0 \quad (8)$$

where ψ_j is the course of the j -th encountered ship, and ζ is the span of the parabola arms.

The elliptic form of constraint (5) is calculated using formula:

$$g_j^e(X_j, Y_j) = (X_j \sin \psi_j + Y_j \cos \psi_j - C_{dj})^2 B_{dj}^2 + \\ + (X_j \cos \psi_j + Y_j \sin \psi_j)^2 L_{dj}^2 - B_{dj}^2 L_{dj}^2 \leq 0 \quad (9)$$

where C_{dj} is the focal distance of the ellipse, L_{dj} , B_{dj} are the axes of the ellipse that are called *dynamic length beam* of the ship and can be computed using:

$$L_{dj} = 1.1L(1 + 0.345V^{1.6}), \quad B_{dj} = 1.1(B + 0.767LV^{0.4}) \quad (10)$$

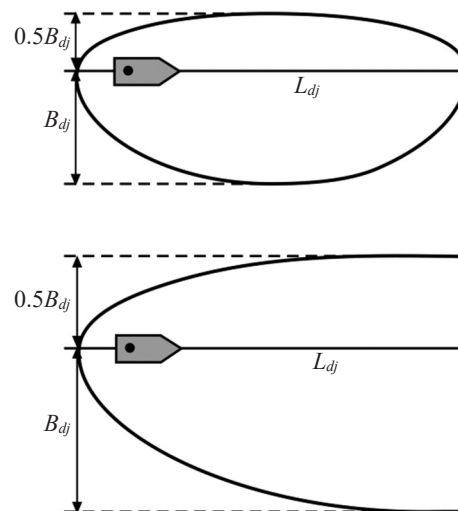
In equations (10), L and B denote the length and beam of the ship, and V is the ship velocity. The basic parameter of the hexagon shape domain is the distance between centre point of ship and bow-point of the domain, L_{dj} .

Neural ships domains

We now consider a network that has five inputs and one output, with the aim of identifying one of the acceptable values of the response, with the smallest error possible, to particular input vectors:

$$\mathbf{y} = \Gamma [W \mathbf{x}] \quad (11)$$

$$\mathbf{x} = [P_j \psi_{wj} V, V_j | V_{wj}] \quad (12)$$



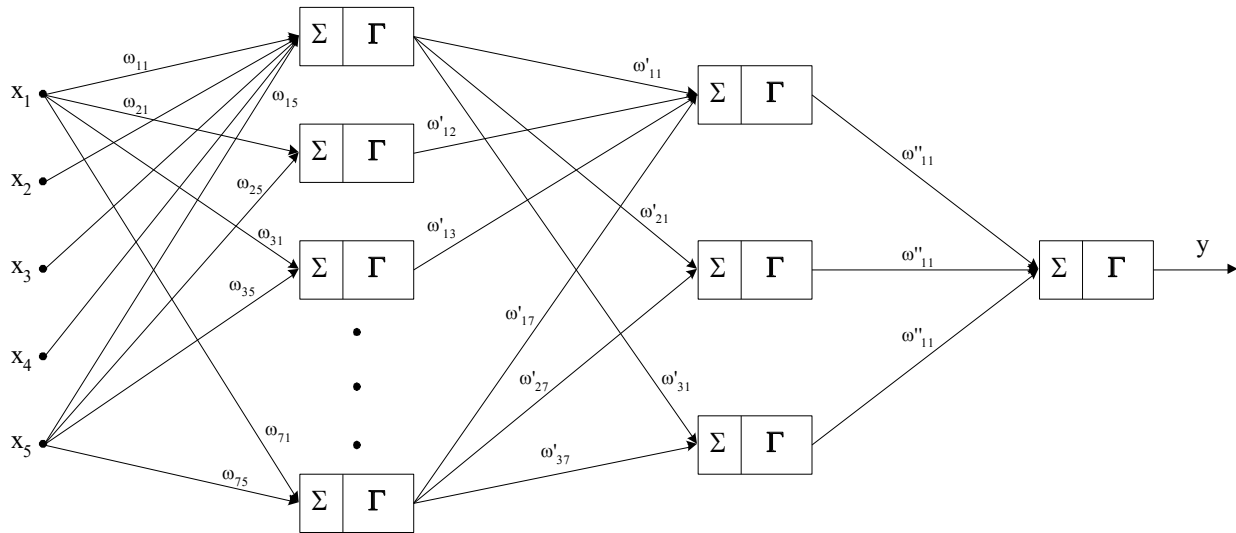


Figure 3. The structure of the neural network generating the ships domains

$$y = [0,1 - \text{safe situation}; 0,3 - \text{attention}; 0,5 - \text{risk of collision}; 0,7 - \text{dangerous situation}; 0,9 - \text{collision}] \quad (13)$$

the following result is found:

$$\min_{\Gamma} \{ \Sigma (y_k - y_{ek})^2 \} \quad (14)$$

where y_k is the network response, y_{ek} is the expected network response, Γ the activation functions of neural network layers, P_j the position of the j -th encountered ship, V_j the speed of the j -th encountered ship, V the speed of one's own ship, ψ_{wj} the relative course of the j -th encountered ship, $|V_{wj}|$ the relative speed, and k the index of time moment (Figure 3).

The values of the elements of the x_k vector are provided from the ARPA system, and the y_k values determine the degree of the collision risk through the dimension of the domain assigned to the j -th encountered ship (Hertz, Krogh & Palmer, 1991; Hunt, Irwin & Warwick, 1995).

The one-way network has three layers of neurons. The non-linear activation functions in the first and second layers represent a tangent nature and the output layer represents the sigmoidal nature. The network was modelled with the use of the Neural Network Toolbox from the MATLAB package. The learning process used the algorithm of the back

propagation of the error with adaptive learning rate and the *momentum*. The learning data were prepared by simulating navigational situations and recording corresponding expected network answers given by an experienced navigator.

Dynamic optimisation of safe trajectory

The determination of the optimal control of the ship in terms of an adopted index of the control quality may be performed by applying Bellman's principle of optimisation. The principle describes the basic features of the optimal strategy – whatever the initial state and decisions are, the remaining decisions must generate the optimal strategies from the point of the state resulting from the first decision. It results from this that the calculations using this method are usually initiated from the final stage and then the process goes toward the first one (Bellman, 1957).

The process of the collision prevention fulfils the duality conditions, therefore the optimal trajectory of the ship under a collision situation is determined using the optimisation principle and is commenced from the calculation of the first stage and is then directed toward the final stage (Lew & Mauch, 2007).

The optimal time for the ship to go through k stages is determined as follows (Eq. 15):

$$t_k^* = \min_{u_{1,k-2}, u_{2,k-2}} \left\{ t_{k-1}^* [x_{1,k}, x_{2,k}, x_{3,k-1}, x_{4,k-1}, x_{5,k-1}, x_{6,k-1}] + \Delta t_k [x_{1,k}, x_{2,k}, x_{1,k+1} (x_{1,k}, x_{3,k} (x_{3,k-1}, x_{4,k-1}, x_{4,k-2}, u_{1,k-2}, \Delta t_{k-2}), \Delta t_{k-1}), x_{5,k} (x_{5,k-1}, x_{6,k-1}, (x_{6,k-2}, u_{2,k-2}, \Delta t_{k-2}) \Delta t_{k-1}), x_{2,k+1} (x_{2,k}, x_{3,k} (x_{3,k-1}, x_{4,k-1} (x_{4,k-2}, u_{1,k-2}, \Delta t_{k-2}, \Delta t_{k-1})) x_{5,k} (x_{5,k-1}, x_{6,k-1} (x_{6,k-2}, u_{2,k-2}, \Delta t_{k-2}, \Delta t_{k-1})), x_{5,k} (x_{5,k-1}, x_{6,k-1} (x_{6,k-2}, u_{2,k-2}, \Delta t_{k-2}, \Delta t_{k-1}))] \right\} \quad (15)$$

$k = 3, 4, \dots, K$

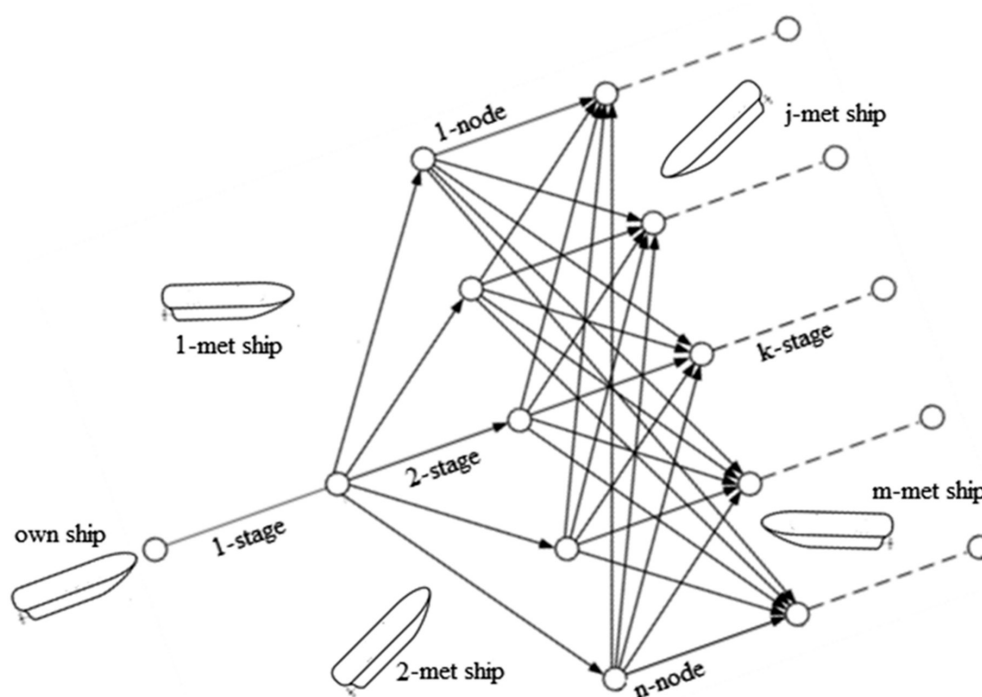


Figure 4. Determination of the ship's safe and optimal trajectory by means dynamic programming method

The optimal time for the ship to go through the k stages is a function of the system's state at the end of the $k-1$ stage and control $(u_{1,k-2}, u_{2,k-2})$ at the $k-2$ stage (Figure 4).

By going from the first stage to the last one, formula (15) determines Bellman's functional equation for the process of the ship's control by the alteration of the angle of the rudder angle and the rotational speed of the propeller. The constraints for the state variables and the control values generate the *neural constraints* procedure in the computer algorithm *dynopttraj* for the determination of the safe ship trajectory.

The consideration of the constraints resulting from maintaining a safe approaching distance and the recommendations of the way priority law is performed by checking whether the state variables have not exceeded constraints in form of neural domains in each of the intersections considered and by rejecting the intersections in which the excess has been discovered (Speyer & Jacobson, 2010; Guenin, Konemann & Tuncel, 2014).

Computer simulation

The trajectories have been computed by means of the *dynopttraj* programme for the ship's situations recorded in the Kattegat Strait, both for conditions of good and restricted visibility at sea (Figures 5–7).

Conclusions

The synthesis of safe and optimal control of the ship improves the problem of steering using the dynamic programming method with a relatively precise description of the dynamic properties.

The synthesis of the steering process described in this paper (concluding with a description of appropriate algorithms for determining the optimal control procedures) forms a basis for the development of a computer program for the definition of the safe trajectory of a ship with the use of information from the on-board anti-collision system.

The safe trajectory proposal can be simulated on the display of the ARPA anti-collision system as an additional feature of the system. The navigator is supported in the control of the process of generating and evaluating various options for efficient decision-making.

The neural networks presented in this paper may be used as elements of the systems for the assessment of the safety of the ships passing by the introduction of the possibility to make a current correction of the sizes of ships' domains. They are able to represent the heuristic knowledge in a similar way to an experienced navigator.

The correctness of the assessment of the safety of the passing vessels with the use of the networks depends, to a decisive degree, on the correctness of

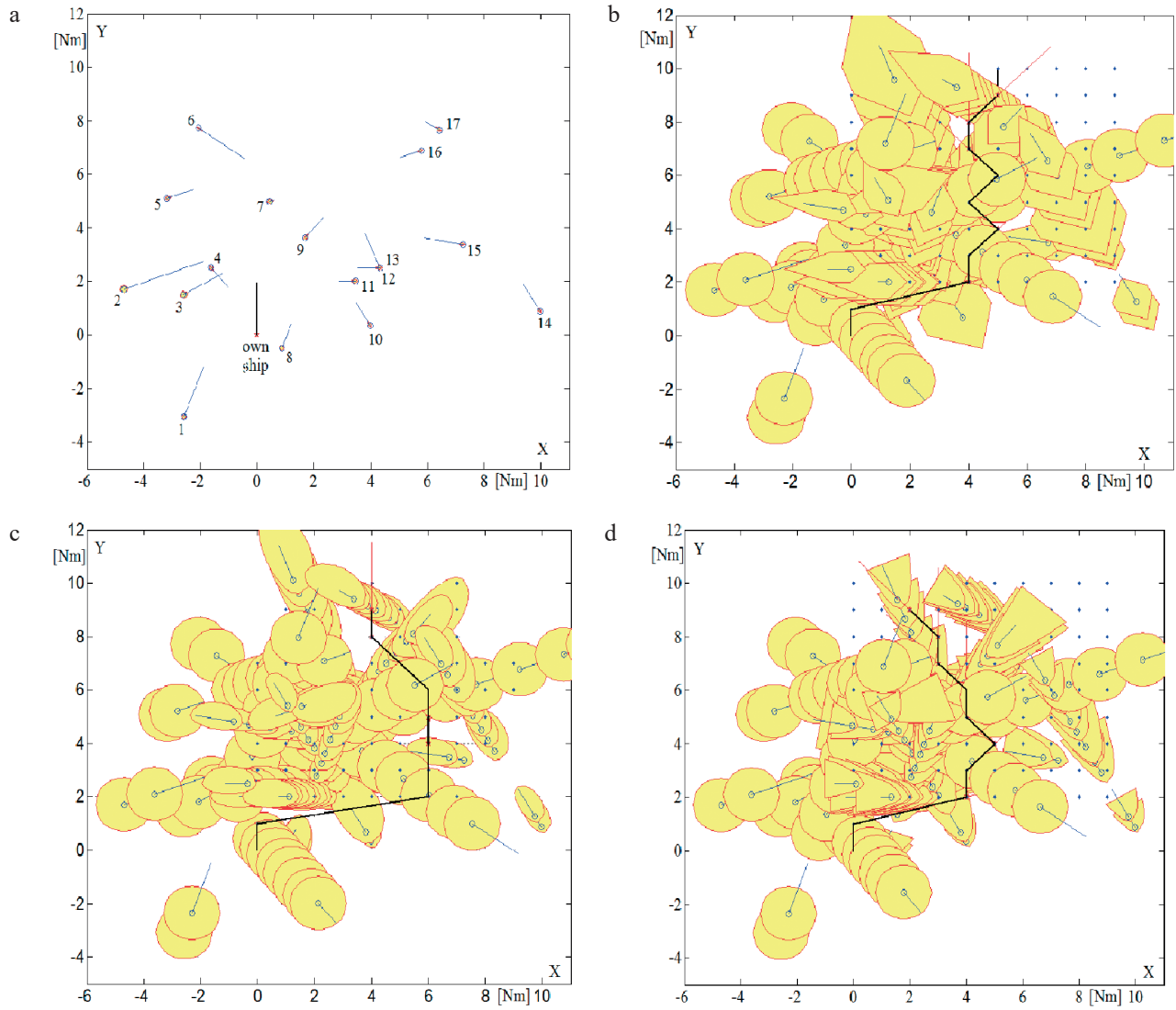


Figure 5. Comparison of safe ship trajectories for different domain shapes in case of 17 met ships and good visibility at sea, $D_s = 1.0$ nm: a – 12 minutes velocity vectors of ships, b – circle and hexagonal domains $t_k^* = 4211$ s, c – circle and elliptic domains $t_k^* = 4798$ s, d – circle and parabolic domains $t_k^* = 4093$ s

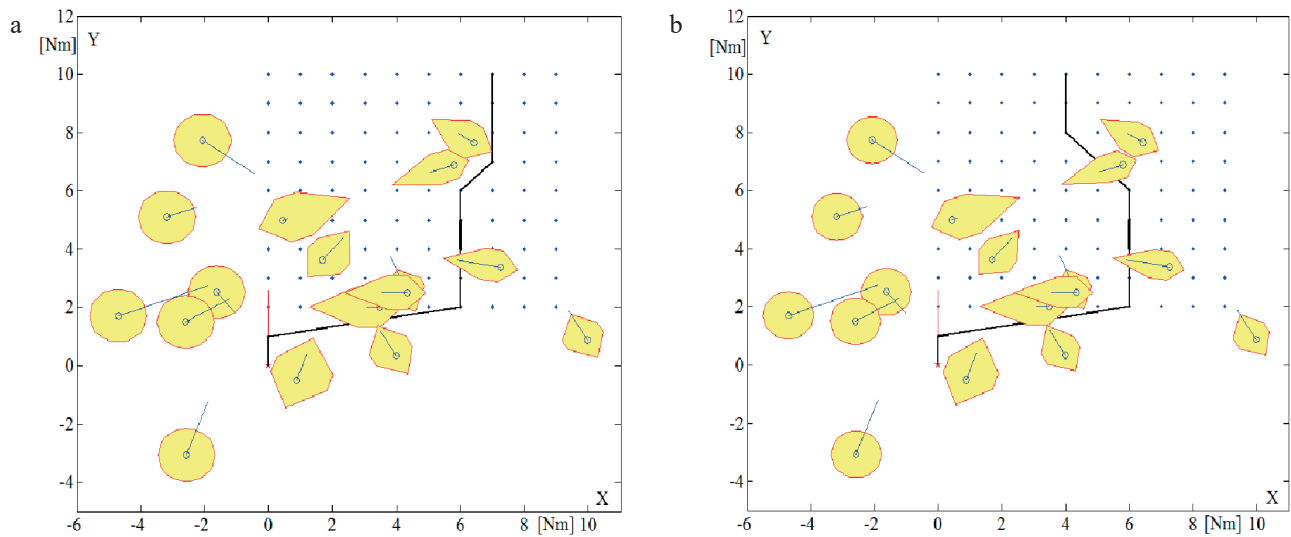


Figure 6. Computer simulation results of the safe ship trajectory in case of 17 encountered ships and good visibility at sea with circle and hexagonal domains: a – $D_s = 0.9$ nm $t_k^* = 4384$ s, b – $D_s = 0.8$ nm $t_k^* = 4499$ s

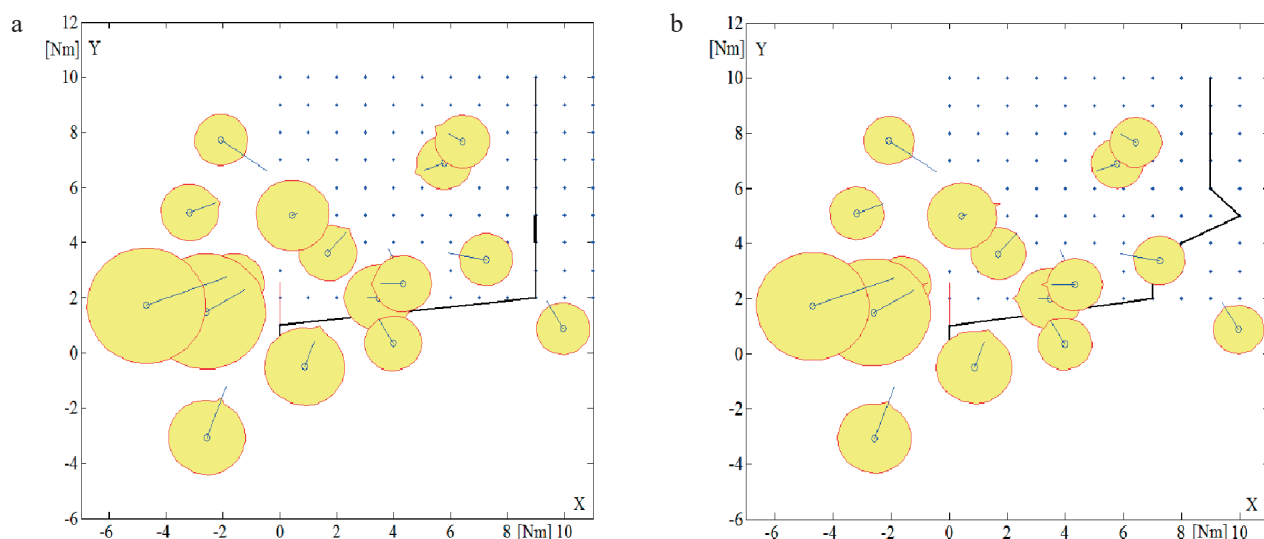


Figure 7. Computer simulation results of the safe ship trajectory in case of 17 encountered ships and restricted visibility at sea with circle domains: a – $D_s = 1.5$ nm $t_k^* = 5092$ s, b – $D_s = 1.4$ nm $t_k^* = 5022$ s

the data used in the process of the learning network. The use of the knowledge of a few experienced navigators during the learning by the network may lead to the situation in which the network acquires their averaged knowledge.

The introduction of elements of the computational intelligence, represented by a properly prepared network, to determine the ship's domain and, as a consequence, safe trajectory in a collision situation, may help less experienced navigators in the supervision of the anti-collision system assisting the navigational situation, increase the safety of the anti-collision manoeuvre and accelerate the process of selecting a manoeuvre to avoid the collision.

Acknowledgments

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The influence of economic and geographic conditions on the development of container terminals at the Szczecin and Świnoujście Seaports Authority

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Key words: channel, container handling, capacity, fairway, rail, basin, TEU

Abstract

This publication describes the factors governing the development of containerization in Szczecin and Świnoujście Seaports Authority, together with their organizational infrastructure and economy. These factors include port access to transportation facilities, which has a major influence on economic development and strengthens the position in the Polish market. Geographic location of both the port and the status and functioning of the Szczecin-Świnoujście fairway were taken into account. The amount of container handling in the ports described in the years from 2004 to 2015 was examined. The Szczecin and Świnoujście Seaports Authority is discussed in terms of size and progress of its changes, and handling capacity compared to other marine container terminals in Poland.

Introduction

Currently, container transports are the most economic and efficient means of moving goods over large and small distances. Unification of the system breaks down the barriers associated with the movement of containers to different regions of the world. At the same time, cargo handling has been improved, creating new combined means of transport like intermodal and multimodal methods.

All of these new solutions and technologies influencing the development of container transport, aiming primarily to increase capacity and handling, which mainly involves the construction of ships with increasing capacity, as well as the modern container terminals that are able to handle them.

In order not to fall out of the market, and to be competitive in the area of economy, old terminals undergo metamorphosis. First of all, expansion by increasing its facilities, adapting infrastructure in such a way as to handle as much cargo in the shortest possible time and at the lowest possible cost.

Geographical location of the Szczecin and Świnoujście Seaports Authority

The geographical location of the Szczecin and Świnoujście, shown on the map in Figure 1, is an important factor in the development of the maritime economy of the region. Their location creates the shortest sea route leading north, which connects the ports with the Scandinavian countries and the route leading to the east connects the ports of Russia, Lithuania, Latvia and Estonia. The route leading to the western ports connects with all Western Europe. The port of Świnoujście, latitude: 53° 25' N, and longitude: 14° 32' E, is located on the Wolin and Uznam islands, the Karsibór estuary of the Świna. The entrance to the port secures two breakwaters from the East (length 1400 m) and west (approximately 300 m). The port can be entered by ships with a maximum length of 260.0 m, a width of 42.0 m and a draft of 12.8 m. The advantages of this port are primarily its being the largest Polish terminal for dry bulk cargoes, a modern ferry terminal, and a Duty



Figure 1. Chart No. 1296 Hydrographic Office of the Polish Navy: Baltic Sea, Lagoon of Szczecin (UMS, 2014)

Free Zone. Passage waterway from the roadstead in Świnoujście to Szczecin takes 4 hours and the distance is 67 km.

The Port of Szczecin is located in the hinterland of geographic coordinates: latitude 53° 55' N, longitude 14° 15' E. Canal Skolwiński runs north, then the port area runs along the banks of the Oder River, up to Castle Route (Western Odra). From the southern border of the port outlines channel Parnica with basins located at the southern end of Przekop Mieleński.

The eastern boundary extends from the Quay Regalica on the Odra River East, which includes the eastern shore of Przekop Mieleński and the Odra River to the north end of the island Dębiny. In the port of Szczecin are the following basins: Przekop Mieleński, Nowy Przekop, channel Grabowski, channel Dębicki, Duńczyca, channel Wrocław (Industrial), Parnica and Lake Dąbie (UK, Hydrographic Office, 2011; ZMPSiŚ, 2016b; UK, Hydrographic Office, 2014/15).

Important elements that affect the economic competition of the ports of Szczecin and Świnoujście

It is necessary for the improvement of the economy and maintenance of ports in a competitive market to deepen the fairway. For the port of Szczecin, the handling of large vessels is currently impossible. The port of Szczecin is located inland and has a maximum depth of 9.15 m, making it dependent on the Świnoujście. Plans and the commencement of work are associated with huge financial commitment. The project includes not only the work necessary to obtain the desired depth of technical track (12.5 m), which is output from the bottom, transport and storage of excavated material, but also widening the track, the streamlining of navigation devices and their continued maintenance.

A further important element influencing the competitiveness and the importance of ports internationally, is road infrastructure. Containerization as multimodal transport should have transport hubs connected by different means of communication. Ports should adapt their facilities in such a way as to ensure complete transport services of a logistics. The advantage of Szczecin's position inland is the proximity to customers and consignors, resulting in cheaper cost of land transport. Consequently, for the base port of Szczecin, good road connections are very important, providing a possibility of combined transport at a European level through the European

transport network, TEN-T. The main idea is an integrated transport system, which includes a well-developed road infrastructure, waterways and rail that in turn will affect faster and cheaper delivery. Further, the idea is a multimodal integrated transport system, which includes a well-developed road infrastructure, waterways and rail, resulting in faster and cheaper delivery. Another advantage is the integration of European countries and the increasing importance of the transport market of the European Union. Figure 2 shows the Central European Transport Corridor CETC-ROUTE65 (Siergiej, 2009).

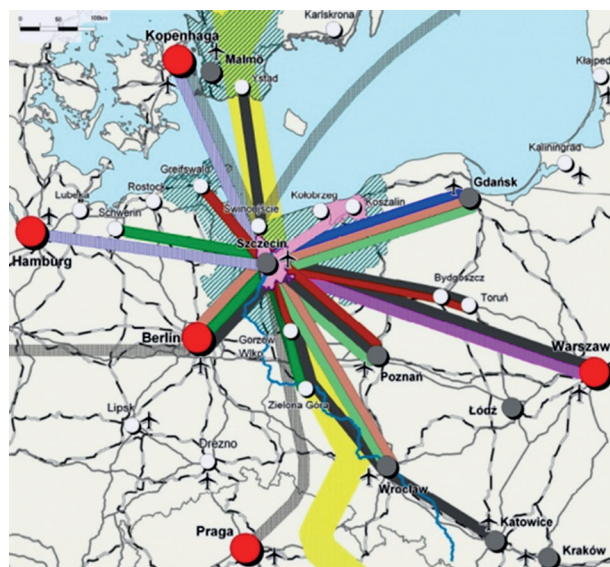


Figure 2. Spatial development plan West Pomeranian Province showing key routes of the West Pomeranian Province at the European and national level (RBGP, 2012)

The General Directorate for National Roads and Motorways (GDDKiA) is responsible for roads and their condition. The GDDKiA performs the following project construction and supervision of public roads and highways:

- S3 expressway Szczecin – Świnoujście, allowing access to the ferry base from which daily ferries depart to Malmö, Ystad and Copenhagen, with a fragment of the E65 international road intersecting with the A6 motorway in Szczecin;
- International road E65 to the Czech Republic via Gorzów Wielkopolski, Zielona Góra, Legnica and Jelenia Góra;
- International road E28 to the Tri-City, Koszalin and Słupsk;
- Connection to the A11 motorway in Western Europe with the Berlin border crossing point in Kołbaskowo;
- National road No. 31: Szczecin – Kostrzyn – Słubice / Świecko;

- National road No. 10: Lubieszyn – Szczecin – Bydgoszcz – Toruń – Płońsk.

The safest, cheapest, but not the fastest land transport container is rail. Railway line C-E59 is part of the corridor of the international connection running from Malmo, Ystad by Świnoujście – Szczecin – Kostrzyn – Zielona Góra – Wrocław, the fork of Chałupki (line E-59) and Międzyzlesie (line C-59/2). Both railways have a connection with international railway lines.

Great significance for increasing economic competitiveness in the ports of Szczecin and Świnoujście is an investment in waterway transport. Across the Odra River, Odra-Hawela channel and national trails, inland ports have direct access to the European network of waterways. Basins and port quays are fully adapted to shipping and handling barges, which are the cheapest mode of transport inland. Unfortunately, in Poland at the present moment, there is no improvement in the conditions for the development of inland navigation. Lack of attention and ineffective measures have led to inhibition of development in this area of economy. The technical conditions of waterways are degraded, together with the disappearance of the fleet ship owners. Inland transport practically no longer exists, and the waterways are traversed mainly by tourists. The primary reason is the lack of financial support from the EU, and the delayed implementation of maintenance work (Toczyński, 2001; Salomonowicz, 2011; Lang Lasalle, 2013; Poland, ZMPSiŚ, 2014).

Assessment of the status and functioning of the Szczecin-Świnoujście fairway

The Maritime Office in Szczecin has developed a project called “Modernization of the fairway Szczecin-Świnoujście”, which is intended to improve the investment offer of the whole region. The project is co-financed by the European Union from the Cohesion Fund under the Program Infrastructure and Environment. The challenge is to deepen the fairway along the entire length to the technical depth of 12.5 m, and to modernize the technical infrastructure of the preservation and protection of the environment. The program is divided into three steps of operation; the first is shown in Figure 3, which began in year 2000 (UMS, 2016).

Due to lack of adequate financial resources and neglect of maintenance, the critical situation on the fairway Szczecin-Świnoujście led some places to shallow below 10 m. The project is aimed primarily at ensuring the safety of shipping ports. Repair of



Figure 3. The stages of modernization (reconstruction) of Świnoujście-Szczecin channel (channels Piastowski and Mieleński) (UMS, 2009)

damaged fortifications and the removal or elimination of hazards during floods; it is only one of many problems with the fairway. Presently, the port of Szczecin call in container ships carrying containers of up to 1600 TEU. More and more frequently, the port of Szczecin is missed out, which exposes “Team Ports” to big losses, and this consequently affects the economic development of the whole region.

In 2013, the second stage of modernizing the fairway was begun. At this stage, the work will focus on the remaining fortifications edge, cutting Piastowski channel to 9.000 km and channel Mieleński to 5.043 km Świnoujście-Szczecin. After the so-called bottom of the channel for cleaning objects, which are not dredged material e.g. the entire project is planned for two years, taking into account the migration of fish in the spring and winter freezing (Poland, Baltic Sea, 2010).

Analysis of container handling in the Szczecin Świnoujście Ports Authority

Since 2004, the Ports Authority has a two-container terminal. In 2012, the company OT Logistics SA, bought part of DB Schenker Rail Poland SA, taking a controlling share in the Commercial Port in Świnoujście. The company specializes in bulk cargo, where in 2013 the Świnoujście port handled their record quantity. The bulk goods therefore completely displaced the transshipments container; the terminal in Świnoujście is not currently carrying out the container cargo operation, annexing the planned area of the terminal handling of containers (Radio Szczecin, 2014).

The Port of Szczecin, managed by DB Port Szczecin, supports feeders, loaded in the largest

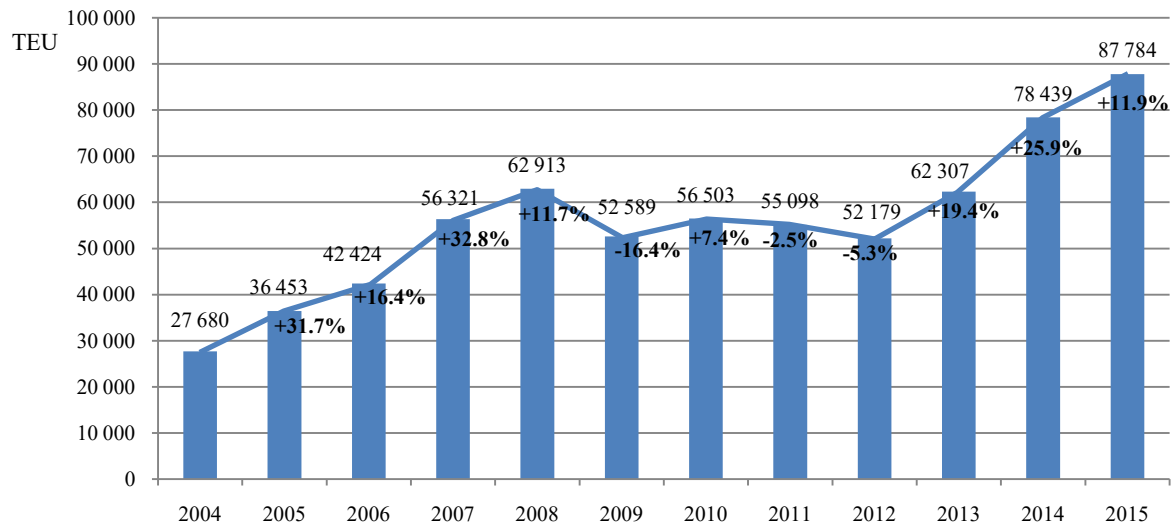


Figure 4. The size of container handling in the years 2004–2015 in Szczecin and Świnoujście Ports Authority [TEU] (ZMPSiŚ, 2016a)

maritime hubs in Europe, i.e., Germany, Belgium, United Kingdom. It also has permanent line services to the UK, Finland, Estonia and Lithuania (DB Port Szczecin, 2016). Figure 4 shows the size of the container handling unit TEU in the years 2004 to 2015, and their annual percentage increase.

From the above graph, it can be observed that in the first years of the period, an increase was recorded. Transshipments in 2004 amounted to 27,680 TEU and gradually increased, reaching these values, along with their annual increment percentages: 2005 – 36,453 TEU (+31.7%), 2006 – 42 424 TEU (16.4%), 2007 – 56 321 TEU (+32.8%), up to 2008, in which the loading and unloading of 62,913 TEU (+11.7%) was more than twice as high as in 2004. The year 2009 is the beginning of DB Port Szczecin's activity, in which there was a significant decrease of 16.4%, giving a result of 52,589 TEU and was caused by the global economic crisis; the collapse of the banking market of the United States, which took place at the turn of the year 2008/2009. Analyzing years of activity has brought positive results. In 2010, rotation increased by 7.4% to 56,503 TEU. The next year noted another, but not as drastic, decrease of 2.5%, giving 55,098 TEU. The downward trend continued in 2012, reducing the transshipment by 5.3%

and closing it to the result of 52,179 TEU. Finally, 2013 brought an increase of 19.4%, giving the result of 62,307 TEU. Container handling in 2014 was 78,439 TEU as a result of a 25.9% increase from the previous year. The last year examined is 2015, which recorded an increase of 12%, giving 87,784 TEU. This significant increase in container handling at the port of Szczecin is the result of strong growth in rotation at the terminal, and the loss of cargo handling in the port of Świnoujście.

The structure of container handling in the Ports Authority against the background marine container terminals in Poland in 2010–2014

Poland currently operates six marine terminals. The largest and most successful two are located in the port of Gdańsk. They are DCT – Deepwater Container Terminal and GCT – Gdańsk Container Terminal. Analyzing the data presented, it can be seen that the container handling in Polish ports is increasing rapidly. From year to year, handling capacity is gradually increasing. Table 1 shows a comparison of container handling at all sea ports in Poland in the years 2010–2015.

Table 1. Container handling in the largest Polish seaports 2010–2015 [TEU] (Port Gdańsk, 2016; Port Gdynia, 2016; ZMPSiŚ, 2016a)

The Years	2010	2011	2012	2013	2014	2015
Gdańsk	511 876	685 643	928 905	1 177 623	1 212 054	1 091 202
Gdynia	485 255	616 441	676 349	729 607	849 123	684 796
ZMPSiŚ	56 503	55 098	52 179	62 307	78 439	87 784
Poland	1 053 634	740 082	1 657 433	1 969 537	2 139 616	1 863 782

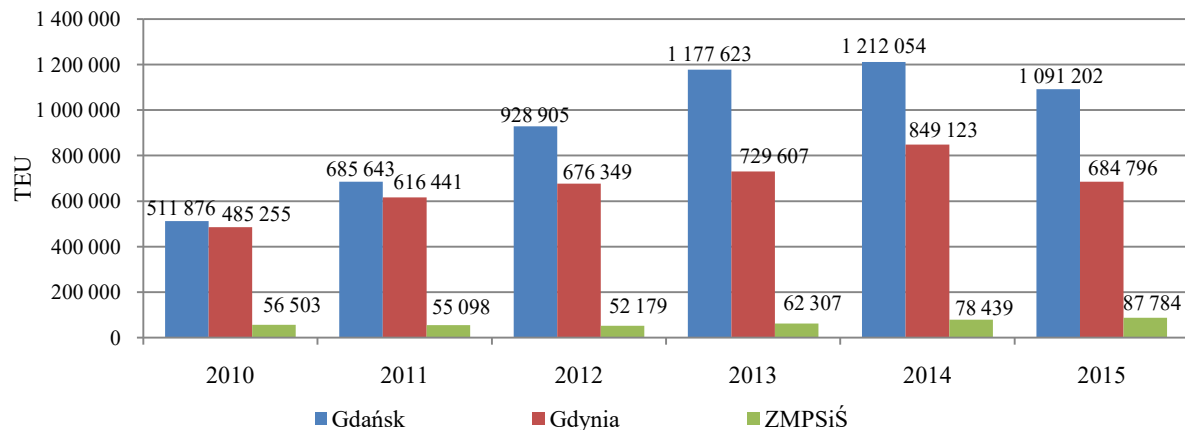


Figure 5. Container handling in the biggest Polish seaports in 2010–2015 [TEU]

Figure 5 was obtained on the basis of the data shown in Table 1, shows the container handling in the biggest Polish seaports.

Figure 6 is characterized by container handling in 2010–2015 with regard to the increase in percentage on the basis of Table 2. It shows that in 2011, the Szczecin and Świnoujście Seaports Authority had the only decrease in transshipment compared to the previous year by 2.5%, and maintained the negative tendency in 2012 with a result of 5.3%. A trend of decline was noted until the end of 2012 and 2013 brought an increase reaching 19.4%, which increased even more in 2014 to almost 26%. Most transshipments were recorded in the port of Gdańsk, then in the port of Gdynia, with the Szczecin and Świnoujście Ports Authority coming last. At the

beginning of the analyzed period of 2010, the ports of Gdynia and Gdańsk only slightly differed in the amount transshipments. This difference begins to increase significantly from 2011 to the advantage of the port of Gdańsk, with a 33.9% increase, and in 2012, improving slightly to 35.5%. In May 2011, a new era was initiated for the DCT in the port of Gdańsk, by establishing cooperation with the world’s largest ship owner, Maersk Line. At the same time, DCT terminal has become the only container terminal in Poland that supports 10 lines AE, connecting Asia with Europe.

Currently, cargo rotation analysis shows that the containerization achieved another major record. Polish seaports serviced more than 2 million TEU by 2014 already. The best result for the

Table 2. Percentage increase in container handling in the biggest Polish seaports 2010–2015 [TEU]

The Years	2011–2010 [%]	2012–2011 [%]	2013–2012 [%]	2014–2013 [%]	2015–2014 [%]
Gdańsk	33.9	35.5	26.7	2.9	–10
Gdynia	27	9.7	7.9	16.4	–19.4
ZMPSiŚ	–2.5	–5.3	19.4	25.9	11.9
Poland	28.8	22.1	18.8	8.6	–12.9

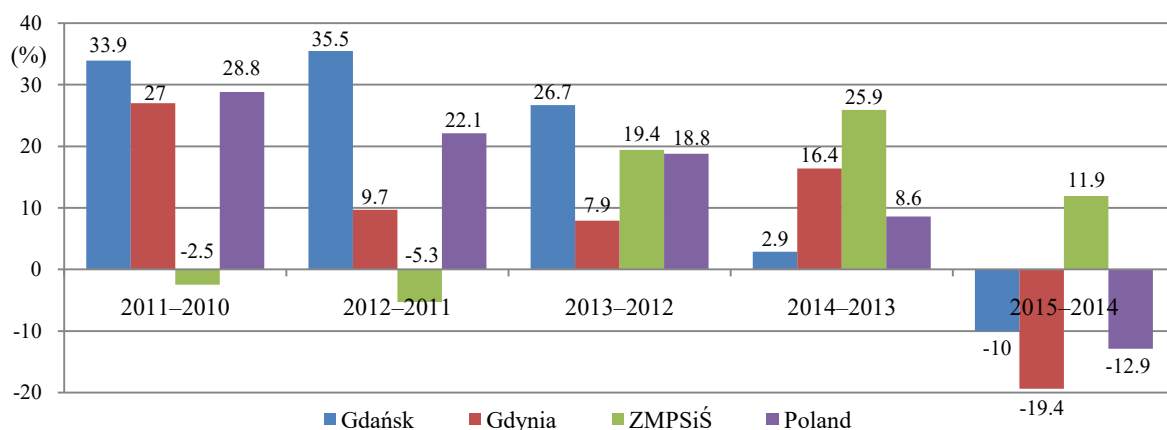


Figure 6. Percentage increase in container handling in Poland in years 2010–2015

period 2014–2013 reached a port in the Szczecin and Świnoujście Ports Authority, where the increase was almost 26%. After the Szczecin and Świnoujście Ports Authority, with the result of 16.4%, came the port of Gdynia, while an increase of 2.9% was obtained in the port of Gdańsk. It should be noted that the 2.9% in Gdańsk gives a greater value of the TEU (34,331) than the 25.9% obtained by the Szczecin and Świnoujście Ports Authority (16,132 TEU) between 2014 and 2013. However, it should be noted 2015 was not as good as 2014 for all Polish ports; only Szczecin and Świnoujście Sea Port Authority recorded an upward trend in the last examined year of 2015 with the result of almost 12%.

Conclusions

Investments made in Polish seaports are evidence of the increasing demand for container transport by sea. EU support for the modernization and improvement of the road infrastructure of different modes of transport is mainly an economic dimension. Poland is not growing in this direction and becomes the proverbial “bottleneck”, so favored by EU policy, aims to create an integrated multimodal transport system. The construction of the Trans-European Transport Network seeks to integrate in such a way as to ensure good road, rail, and inland with port facilities of Szczecin and Świnoujście. These changes also have increased the importance of Polish ports to handle transit traffic.

The Szczecin and Świnoujście Ports Authority would have developed faster, but the development has been slowed by constant deterioration of the deepened fairway where modernization is associated with high financial investment.

The described terminals in Szczecin and Świnoujście continuously change in terms of improving handling operations. The Szczecin and Świnoujście Ports Authority when compared to the ports of Gdańsk and Gdynia is far behind in terms of cargo handling. This can be explained mainly by the increased possibilities provided by deep water in a channel (Szczecin will not to be a deep-water port like Gdańsk). The situation of not handling containers in Świnoujście has been temporality stopped. The terminals still exist and there are the plans to reactivate them, but no particular date has been issued. The data analyzed in this study covered the period of container handling in the Szczecin and Świnoujście Ports Authority presented during its best and worst years. This included the crisis in the global market (2009), in which there was a decrease of as much as

16.4%. The most productive period in the analyzed period was 2014 with almost 26% increase. In total, Poland reported a nearly 13% decrease in the last analyzed year (2015). The Świnoujście terminal, compared to Szczecin, is not particularly strong. There were attempts to increase its handling capacity for example the purchase of a crane in 2013. However, the company specializes in bulk cargo, which achieve excellent results, and therefore deeper analyses of the container terminal in Świnoujście would not yield particularly valuable findings.

For comparison, further analysis showed that handling in the ports of Gdańsk and Gdynia (2010–2015) increased up to 2014. During the last analyzed year a decrease was observed, which affected the result of container handling in all Polish ports. Operation of the world’s largest owner means that the port in Gdańsk is constantly expanding its facilities and handling capacity. As a result of the maritime customers at Gdańsk the port was highly evaluated in 2014 and reached a record result of 1,212,054 TEUs.

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Comparison of ship performance optimization systems and the bon voyage onboard routing system

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Key words: ocean routes programming, SPOS system, Bon Voyage system, ocean routes optimization, safety of navigation, weather navigation, weather routing

Abstract

A significant increase in demand for navigation support systems called Onboard Routing Systems (ORS) can be observed in the World's merchant fleet. ORS is a navigation-support system that enables route programming to warn of dangers and navigation constraints and determine the required route-safety level directly onboard the vessel. In this article, an attempt to analyze and compare two ORS systems has been made: the Ship Performance Optimization System (SPOS), by the Meteo Consult Group; and the Bon Voyage system by Applied Weather Technologies (AWT). Individual items, methods, and criteria of both systems for optimization and weather forecasting models utilized have been compared. Particular attention has been paid to the usefulness of the systems regarding the problem of identification and avoidance of hazards such as tropical cyclones and wave resonance. Ergonomics of both systems has also been compared.

Introduction

Vessel safety and the economic results of a voyage depend on many factors. One such factor is undoubtedly the way in which the ocean voyage of a ship is planned and executed – that is, the optimization of the ocean route according to a given criterion (e.g. the minimal time en route, minimal voyage cost, fixed voyage time) keeping a required safety level. In this article, a comparative analysis of two onboard tools (ORS – onboard routing systems) serving that purpose have been made. They are the Ship Performance Optimization System (SPOS) by the Meteo Consult Group and the Bon Voyage System by Applied Weather Technologies (AWT) (Meteo Consult BV, 2009; Applied Weather Technologies, 2014).

Description of weather data

In both systems, weather data are received onboard as a compressed weather file containing all

weather information, prognosis, and analysis. Their decoding and reading are only possible with the use of the dedicated, weather-optimization, software tools.

Users of the SPOS system have a choice of ocean and coastal regions for which the weather data will be received. There are 7 ocean regions (North Atlantic, South Atlantic, Indian Ocean, North Pacific, South Pacific, Arctic Region, and Antarctic Region) and 6 coastal regions (European, North American, South American, African, Asian, and Australasian). Another division and choice of sub-regions in each of the coastal regions are available. Weather data can be ordered for a maximum of 4 ocean or coastal regions in a standard or extended format for 3, 5, or 9 days and in low or high resolution. Weather data for coastal regions is available for only 5 days. Weather files are not ship-specific; they can be decoded and read on any SPOS system application (Wiśniewski, Wielgosz & Korwin-Piotrowski, 2012; Applied Weather Technologies, 2014).

In the Bon Voyage system, the user can freely determine the geographical borders of the region for which the weather data will be received by defining its geographical latitudes and longitudes. Weather data, together with the types of required weather elements, can be ordered for a period of 1 to 16 days. Irrespectively of the user's preferences, information on the pressure, fronts, tropical systems, and ice-bergs are always included (Applied Weather Technologies, 2014). Weather files are ship-specific; it is only possible to read them on a system dedicated for the use on a specific ship (Applied Weather Technologies, 2014).

A comparison of the SPOS and Bon Voyage systems regarding the aspect of accessible weather data is presented in Table 1. Mark "e" at the mark "X" in a column for SPOS system means that a given weather element is available in an extended format.

A received weather file has to be uploaded in the route optimization software. In the SPOS system, it is done by copying the file into a defined catalogue on a hard drive and then updating the weather in the software. The system will upload the latest-by-date weather file available in the default catalogue. In the Bon Voyage system, it is only necessary to double-click the received weather file to upload the file into the system and update the data.

The size of the weather file depends on the amount and type of weather data contained in it. A weather

Table 1. Comparison of SPOS and Bon Voyage systems: accessible weather data [authors' findings based on (Meteo Consult BV, 2009; Applied Weather Technologies, 2014)]

Weather element	SPOS	Bon Voyage
Atmospheric pressure	X	X
Tropical systems	X	X
Fronts	X	X
Wind, direction and velocity	X	X
Significant waves h1/3, direction, height, period	X	X
Swell, direction, height, period	X	X
Seas	X	X
Rogue waves		X
Pressure for 500 hPa level	Xe	X
Weather type	Xe	X
Precipitation	Xe	X
Clouds		X
Air temperature	Xe	X
Sea surface temperature	Xe	X
Visibility	Xe	X
Air humidity		X
Surface current, direction and velocity	X	X
Ice bergs and ice pack	Xe	X
Vessel's icing		X

file for a sample route has been comprised in both systems to compare the size of such a file. The sample route was from Vancouver to Pusan along the great circle line through the Bering Sea. Weather

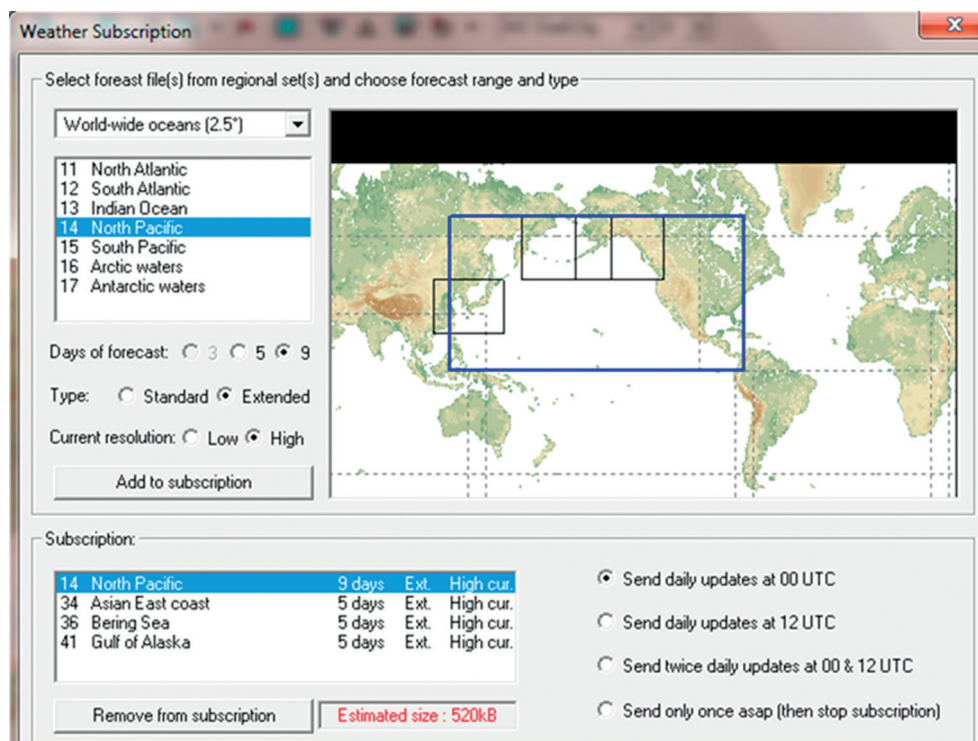


Figure 1. An example of a weather file ordered in the SPOS system for a voyage from Seattle to Pusan (Meteo Consult BV, 2009)

Data Request Estimated Forecast Size: ~516.8KB

Main Area | High-Res | **Item Select** | Satellite Image | Port Vicinity Fcst | Delivery Schedule | Summary

Area

Coordinates: 65N, 120E, 120W, 20N

Forecast Length: 16 Days

Estimated Forecast Size: ~516.8KB

Main Area | High-Res | **Item Select** | Satellite Image | Port Vicinity Fcst | Delivery Schedule | Summary

Category	Item	File Size
Atmospheric Weather	<input checked="" type="checkbox"/> Pressure, Tropicals and Fronts are always included	~15.8 KB
	<input checked="" type="checkbox"/> Wind	~93.5 KB
	<input checked="" type="checkbox"/> 500MB Height	~3.1 KB
	<input checked="" type="checkbox"/> Visibility	~15.0 KB
	<input checked="" type="checkbox"/> Precipitation	~31.9 KB
	<input type="checkbox"/> Cloud Cover	
	<input checked="" type="checkbox"/> Air Temperature	~2.3 KB
	<input checked="" type="checkbox"/> Humidity	~42.4 KB
Ice	<input checked="" type="checkbox"/> Pack Ice & Bergs are always included	~38.0 KB
	<input checked="" type="checkbox"/> Vessel Icing	~77.5 KB
Waves	<input checked="" type="checkbox"/> Significant Wave	~54.9 KB
	<input checked="" type="checkbox"/> Swell	~43.2 KB
	<input checked="" type="checkbox"/> Seas	~28.6 KB
	<input checked="" type="checkbox"/> Rogue Wave	~4.8 KB
Ocean	<input checked="" type="checkbox"/> Current	~64.1 KB
	<input checked="" type="checkbox"/> Sea Surface Temperature	~1.7 KB
Others	<input type="checkbox"/> Marine Bulletins	
	<input type="checkbox"/> Piracy Reports	

Cancel << Back Next >> Finish

Figure 2. An example of a weather file ordered in the Bon Voyage system for a voyage from Seattle to Pusan (Applied Weather Technologies, 2014)

data and elements in both systems were configured to be as similar as possible. The results are presented in Figures 1 and 2. The sizes of the files are very similar. In the SPOS system, the size of the weather file is 520 kb, and in the Bon Voyage, the file is 517 kb.

Weather simulation in the SPOS system is available for 9 days; past that time, the system uses the climatic data (*Routing Charts*). In the Bon Voyage system, weather simulation is available for 16 days; past that time, weather simulation is not possible. Climatic data are not available in the system.

The difference between the systems is very significant, in particular when the voyage lasts 2 – 3

weeks. With 16 days of weather forecasts in the Bon Voyage system, forecasts for the period from day 10 until day 16 can be regarded as a long-term outlook, which seems to be better than adoption of the middle-term climatic data as is done in the SPOS system.

In both system, their own specific weather-forecasting systems are used, based on various weather models, world, local, and own.

Sources of weather data and weather models of the SPOS system are described in Wiśniewski, Wielgosz, & Korwin-Piotrowski (2012). Reception of the weather data in the SPOS system is possible once or twice daily, at 0000UTC and 1200UTC.

In the Bon Voyage system, weather data are from the following sources (Applied Weather Technologies, 2014):

- Surface barometric pressure and wind, pressure for 500 mbar – NOAA and GFS model;
- Significant waves h1/3, seas and swell – WAVE-WATCH III model;
- Weather forecasts and outlooks, tropical cyclone warnings – National Hurricane’s Centre, JMA, JTWC and local sources;
- Satellite images – Meteosat, MTSAT&GOES;
- Surface currents – Hycom model for first 4 days of the forecast, then own AWT model;
- Iceberg and icepack info – JMA, National Ice Centre, local sources;
- Sea surface temperature – NCEP/MMAB model, with the use of Real Time Global Sea Surface Temperature High Resolution (RTGSSTHR);
- Air temperature, clouds, air humidity – GFS model;
- Weather type – own AWT model, with the use of GFS data as entry data of their own AWT model;
- Visibility, vessel’s icing – NCEP/MMAB model with the use of GFS model data as entry data;
- Rogue waves – own AWT model.

In the Bon Voyage system, weather files are available 4 times daily, at the following times (Applied Weather Technologies, 2014): 0300UTC, 0900UTC, 1500UTC, and 2100UTC. The period of time needed to obtain the weather forecast in relation to the

international meteorological times (0000, 0600, 1200, 1800UTC) is 3 hours. Warnings and forecasts regarding tropical systems (cyclones, storms, and depressions) are also available 4 times daily at the following times (Applied Weather Technologies, 2014): 0400UTC, 1000UTC, 1600UTC and 2200UTC.

Both systems fully comply with the requirements of shipping.

Illustration of a weather situation

In both systems, the basic map-view projection is the Mercator projection. Orthographic projection is also available in both systems, and the Bon Voyage system additionally offers a gnomonic projection. ECA zones are presented and taken into consideration in calculations in the Bon Voyage system only; the SPOS system has no such option.

Ergonomics in both systems are comparable; the user menu is intuitive and working with the system does not cause any problems.

The legibility of weather charts in both systems is different; charts in the Bon Voyage system are less legible than those in the SPOS system (e.g., unnecessary port names, too intensive range of colors, unnecessary graphics not related to weather, unclear symbols of weather fronts). Figures 3 and 4 present the same weather situation for the day 26.08.2015 in both systems.

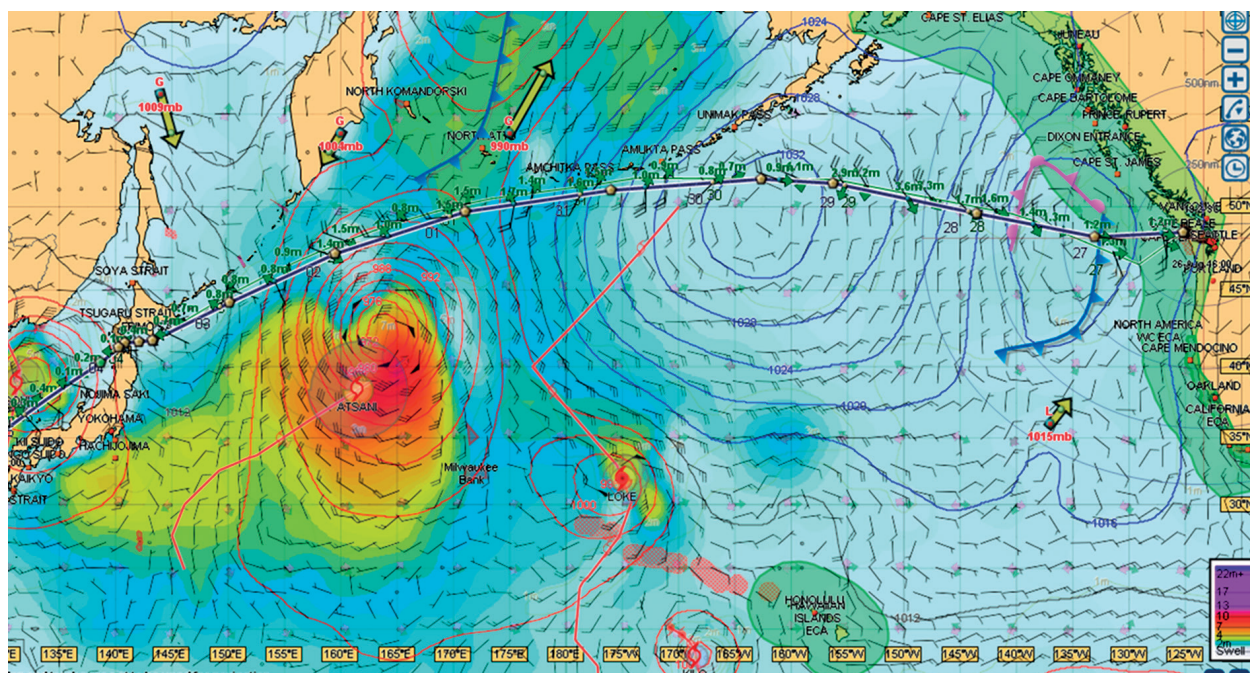


Figure 3. Route Seattle – Pusan optimized in Bon Voyage system, optimization least cost/fuel with fixed arrival time. Weather situation for 26.08.2015 [source: authors’ test using the Bon Voyage system]

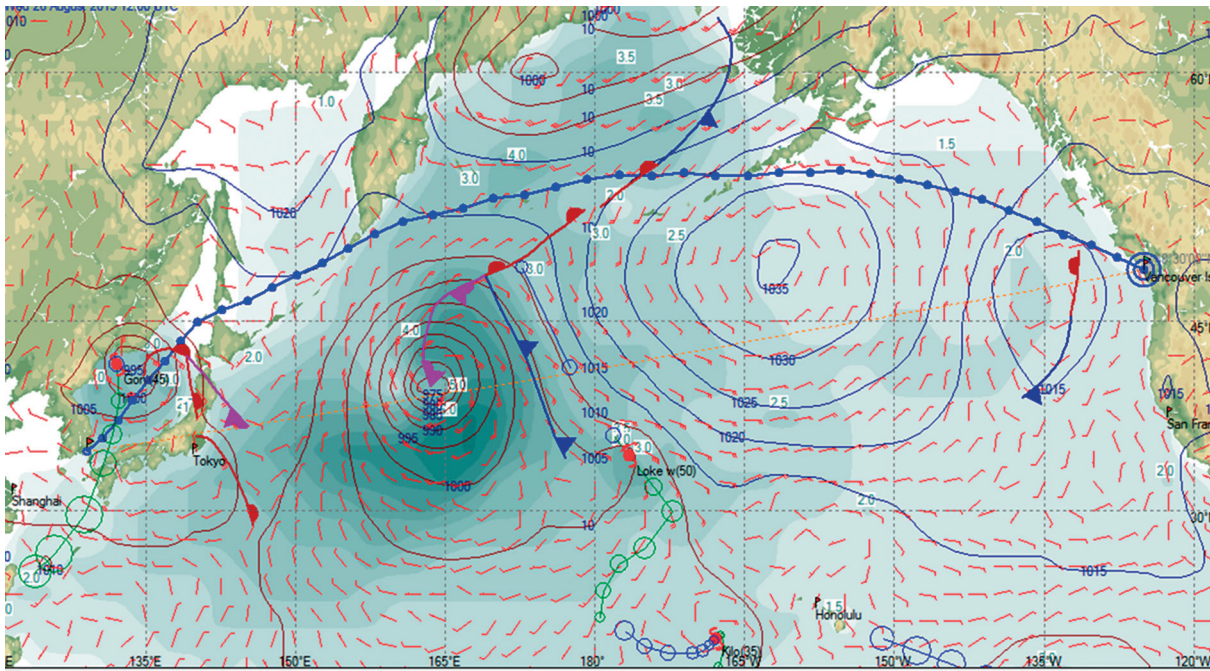


Figure 4. Route Seattle to Pusan optimized in the SPOS system, optimization Optimum High & Wide. Weather situation for 26.08.2015 [source: authors' test using the SPOS system]

There is no option for wide searching of isochrone courses in the Bon Voyage system. Due to this, it was not possible to find the route between the islands of the Kuril Archipelago. In that instance, it is necessary to introduce intermediate waypoints at passes between Kuril Islands.

There is no ECA-zones illustration in the SPOS system. In the Bon Voyage system, ECA zones are taken into consideration by the way of fuel-cost (including two fuel types) calculations in the overall voyage optimization. As a result, the initial waypoints of the great circle in both systems are not the same.

Route optimization – navigational function

In both systems, ocean-routes optimization is performed with the use of the isochrones method. The Bon Voyage system offers 3 modes/criteria of optimization:

- 1) Minimum time en-route – *least time* – the route will be optimized so as to obtain the minimum time of the voyage.
- 2) Minimum fuel consumption – *least fuel* – the route will be optimized so as to obtain the minimum fuel consumption during the voyage.
- 3) Minimum fuel consumption with fixed arrival time – *least fuel with fixed ETA* – the route will be optimized for minimum fuel consumption en-route with a fixed time of arrival at the port of destination.

The least-fuel optimization is, as a matter of fact, a minimal-time-en-route optimization with a given, fixed, calm-sea speed that does not exceed the critical RPM of a ship's main propulsion system. It is not a minimum-fuel-consumption methodology in as described in Wiśniewski (1991).

In the SPOS system, only a minimal time-en-route optimization is available. The calm sea speed must be defined by the user. There are three options for the isochrone-course calculations interval available: 5° (Low), 3° (Medium), and 1° (High). An additional option of „wide searching”, in which the interval between searching courses is doubled, is available (Wiśniewski, Wielgosz & Korwin-Piotrowski, 2012). Such diversity in route-searching options enables the user to create a collection of routes to rank them for safety and choose the route that offers the best possible trade-off between the safety of the voyage and the economical and operational results. In the Bon Voyage system, a collection of routes can only be created manually by arduous programming of each route separately.

Beside the method of route programming, the second factor affecting the efficiency of the route optimization process is the speed-down curves – i.e., the ship's speed characteristics on waves and wind. Makers of both systems present a different approach to this subject.

The Bon Voyage system provides the user with a set of default speed-down curves for a variety of different types of ships: bulkers (cape size, handy

size, handymax, panamax, ULOC, VLOC), car carrier, container vessel (feeder, feedermax, small feeder, new panamax, panamax, post panamax, ULCC), fishing vessel, general cargo vessel, OBO carrier, passenger vessel, reefer, roro vessel, chemical carrier, gas boats (LNG, LPG), tankers (afamax, panamax, suzmax, handy size, VLCC, ULCC), sailing yacht, and motor yacht. The library of speed-down curves is spacious and extensive. They consist of a seas speed-down curve and a swell speed-down curve presented in graphical (diagram) and tabular form. They include percentage values of speed that can be achieved by a ship under the given weather conditions (swell and seas, in Beaufort scale and meters, respectively) in relation to ship speed in calm seas as a function of angle of attack by seas and swell. The angle of attack by seas and swell is described as follows:

- Head – head seas/swell;
- FQtr – forward quarter, angle of attack by seas/swell from forward quarter (0°–90°);
- Beam – angle of attack by seas/swell from abeam;
- RQtr – rear quarter, angle of attack by seas/swell from a stern quarter (90°–180°);
- Stern – angle of attack by seas/swell from the stern (180°).

Gradation of the wind force is according to the Beaufort scale, from 0 to 12. Gradation of swell is from 0 to 18 m, in full-meter increments. The default speed-down curves for a postpanamax container vessel are presented in Figure 5.

Boxes in the tables can be edited to enable fine adjustment of the curves to a specific ship. It is, however, not possible to save the edited curves and tabular values.

In the SPOS system, only one default speed-down characteristic is available (Figure 6). It is not possible to edit it but additional speed-down curves, delivered from the owner’s office, can be downloaded into the system. They can be edited and saved as necessary by the user onboard.

Speed-down curves and characteristics presented in Figures 5 and 6 are similar. They have been used in a true voyage, which is described further in this paper. Speed-down curves of the Bon Voyage system show a certain shortcoming. Usually, true speed-down curves show a certain gain in speed of the vessel in relation to the speed on the calm seas for seas of 0 to 4 m high for quarter and stern angles of attack (120° to 180°). Such a gain in speed, depending on the type of vessel, can be significant; it amounted to 3% for con-ro ships operated by the Polish Ocean Lines on the North Atlantic in the 1970s and 1980s (Wiśniewski, 1991). Default speed-down curves of the Bon Voyage system do not show such a feature.

The way in which constraints and limitations of the voyage-optimization process are programmed into the system is crucial for the process itself. In both systems, a deterministic approach is used.

Figure 7 presents the weather-constraints programming panel of the Bon Voyage system. Only a possibility to define limit values of seas and swell

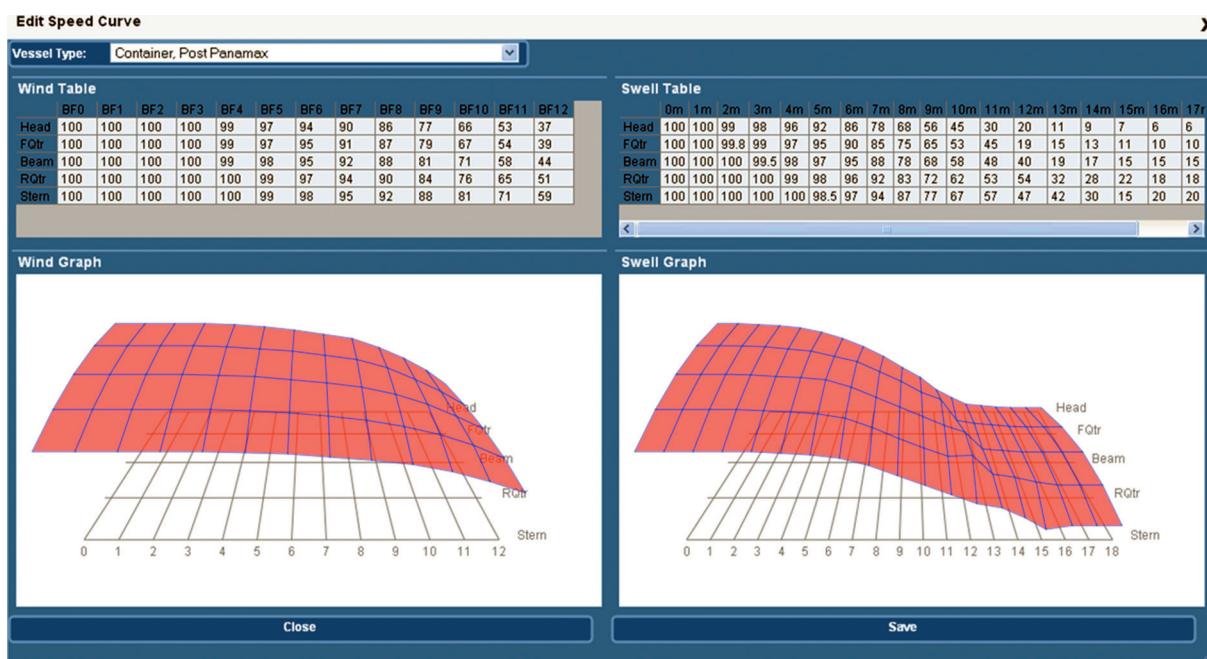


Figure 5. Speed-down curves in the Bon Voyage system (Applied Weather Technologies, 2014)

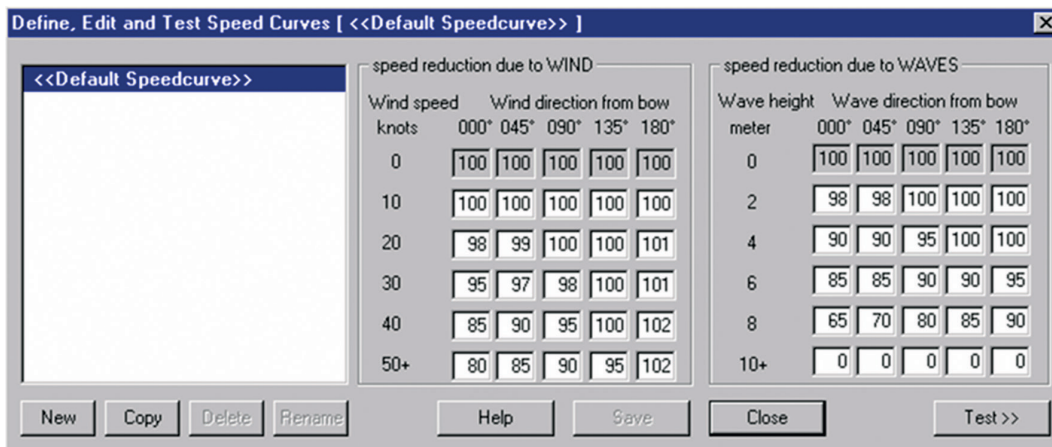


Figure 6. Default speed down curves in the SPOS system (Meteo Consult BV, 2009)

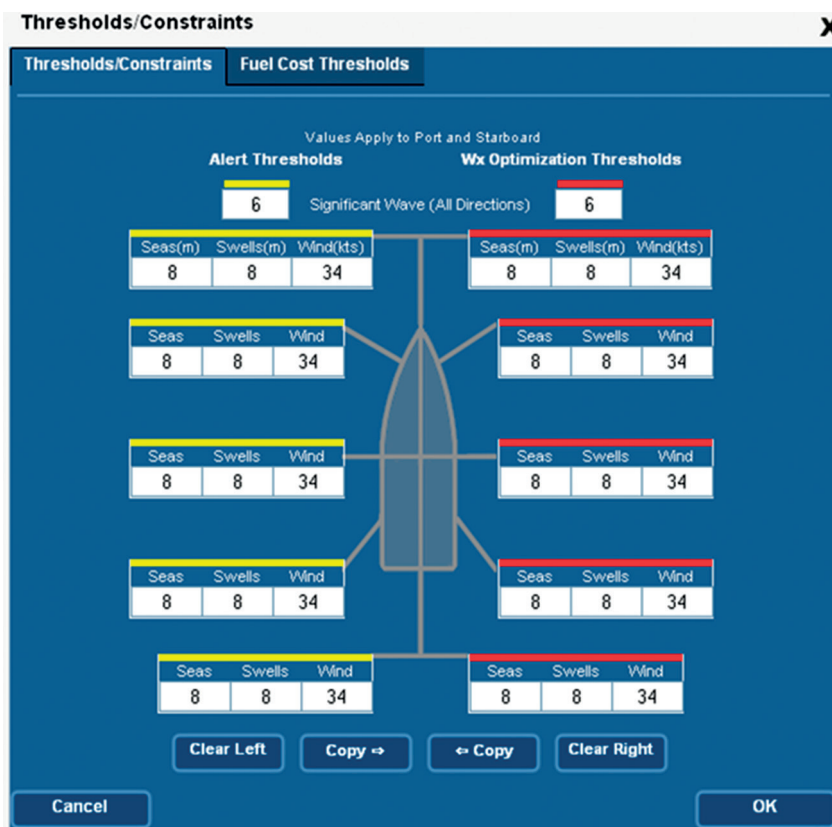


Figure 7. Weather-restriction programming panel in the Bon Voyage system [source: authors' test using the Bon Voyage system]

and wind velocity as a function of angle of attack are available with warning (alert) or avoidance (optimization) options.

In the SPOS system, this issue is solved in a more active way and offers the user more options. The weather-constraints programming panel of the SPOS system is presented in Figure 8. Apart from standard limit values of wind velocity and sea height in the function of angle of attack, the user has other options that significantly increase his or her influence on the voyage-optimization process.

Most importantly, in the SPOS system, the user can define the minimum distance to a tropical system; however, it is not possible to define the rules of avoidance of these systems. Other options include avoidance of bad visibility areas, a vessel's icing risk areas, areas of icepack and icebergs, and vertex – a geographical parallel. The user can also define the critical range of sea and swell heights. All limit values can be declared as to-be-avoided (Avoid – the optimal route will not run through these defined and declared areas) or as a warning only (Warn

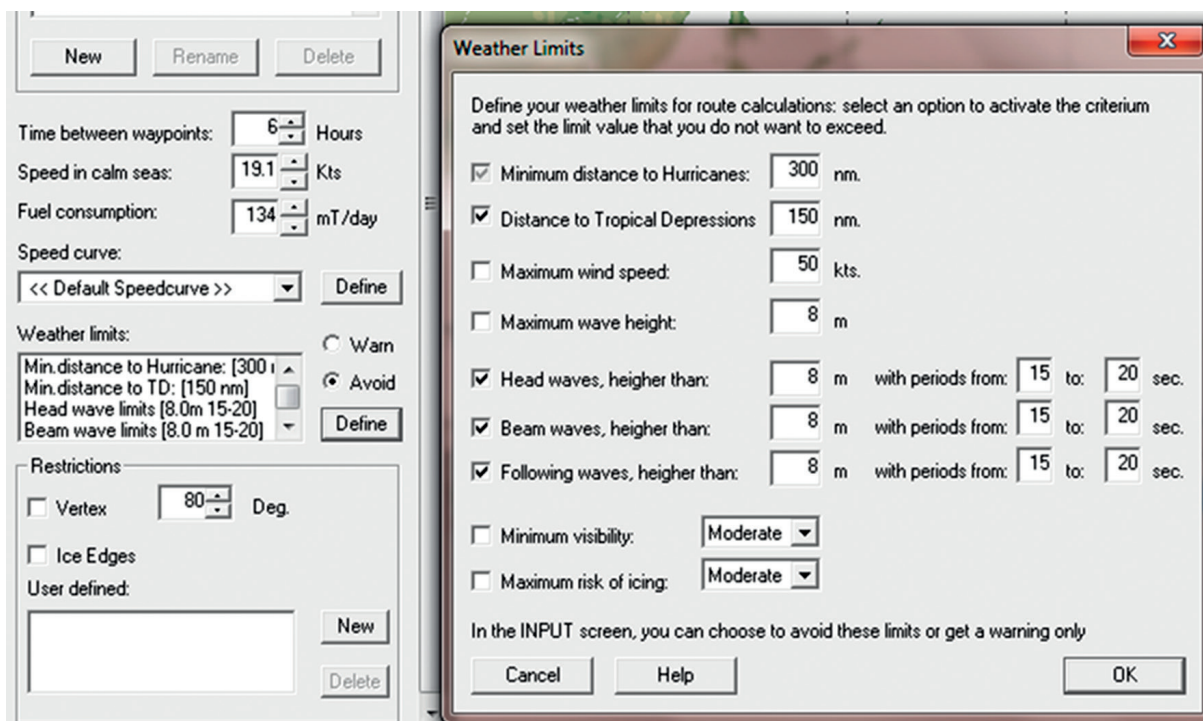


Figure 8. Weather-restrictions programming panel in SPOS system [source: authors' test using the SPOS system]

– the optimal route will lead through these defined and declared areas and the system will display the respective warning for the user).

Illustration of wave resonance

Wave resonance and its influence on a ship's safety during its voyage must be a part of each voyage-optimization process. A very serious shortcoming of the SPOS system is a complete lack of consideration for such information. The system enables only a presentation of a weather situation in the ship's position and cursor's position (Figures 9 and 10). More weather information is available in the cursor's position than in the ship's position, which is also a concern.

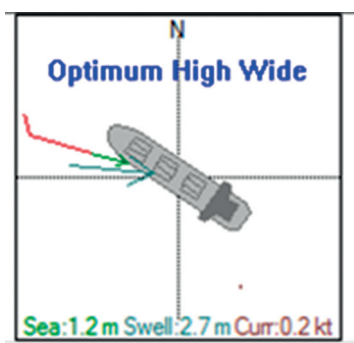


Figure 9. Illustration of weather situation of a ship's position using the SPOS system (Wiśniewski, 1991)

ot Weather	
Lat:	45°21'31"N
Lon:	162°33'09"E
Pressure:	1012 hPA
Wind:	WNW 20 kt
Waves:	2.3 m
- Sea:	WNW 6 s 1.7 m
- Swell:	S 10 s 1.6 m
Current:	SE 0.3 kn
Temperature:	13°C 55F
Precipitation:	3%
Visibility:	good
Seawater temp.:	13°C 55F
Weather:	drizzle
Icing:	None
500hPa	5670 m

Figure 10. Illustration of a weather situation using cursor positions using the SPOS system (Wiśniewski, 1991)

In the Bon Voyage system, this issue is solved satisfactorily. Wave-resonance-data programming and weather-situation presentation in a ship's position is possible in the panel Snapshot (Figure 11). The following data can be programmed:

- Ship's initial stability (GM – initial metacentric height).
- Ship's roll period, calculated after the insertion of the GM according to the IMO formula. However, it can also be amended according to the available ship's documentation or observations onboard.
- Draught means of means calculated on the basis of the declared forward and after draughts.

- Limit values for 4 types of wave resonance: *Parametric Roll*, *Synchronous Roll*, *High Wave*, and *Broaching*.

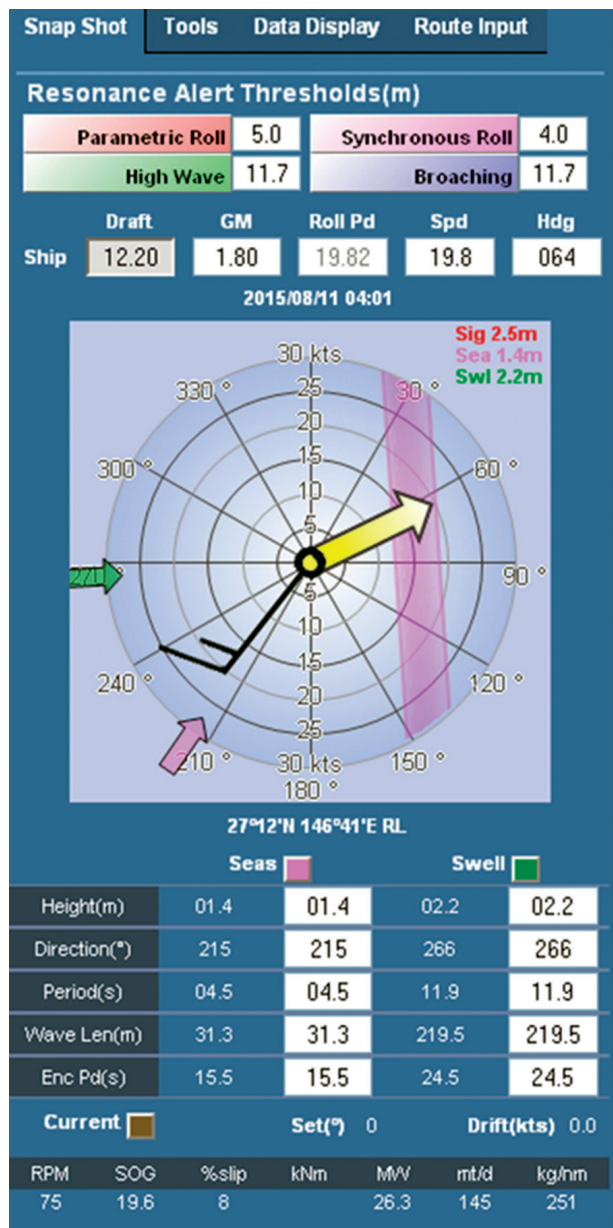


Figure 11. Illustration of wave resonance in the Bon Voyage system (Applied Weather Technologies, 2014)

In case the wave resonance is predicted along the optimized route, the respective alarms will be shown on respective computation points. Detailed information on the risks is available in the Snapshot panel. The system does not optimize the route in such a way as to avoid the areas of wave resonance; such an amendment must be carried out by the user.

The default limit values of the wave resonance that the Bon Voyage system utilizes for its computations are given below. They can, however, be changed, according to the user's preferences.

- *Parametric Roll* – limit values are related to significant wave $h_{1/3}$ by which a phenomenon of a *Parametric Roll* is possible.

LOA – length overall	significant wave limit value
0–124.99 m	3.0 m
125–149.99 m	3.5 m
150–229.99 m	4.0 m
230+	4.5 m

Example: a ship of LOA = 220 m, the correct value is 4.0 m.

- *Synchronous Roll* – limit values are related to significant wave $h_{1/3}$ by which a phenomenon of a *Synchronous Roll* is possible.

LOA – length overall	significant wave limit value
0 – 124.99 m	3.0 m
125 – 149.99 m	3.5 m
150+	4.0 m

Example: a ship of LOA = 140 m the correct value is 3.5 m.

- *High Waves & Broaching* – limit values are related to significant wave $h_{1/3}$ by which a phenomenon of a *High Waves & Broaching* is possible and calculated according the following formulas:

Significant wave limit value = 0.04 LOA [m] for ships of LOA below 275 m;

Significant wave limit value = 0.035 LOA [m] for ships of LOA above 275 m.

Fuel consumption on a selected route

An important item for ocean-route optimization of least fuel with fixed arrival time type is the knowledge of a fuel-consumption curve for various speeds of the ship through the water or various RPMs of the ship's main propulsion system.

In the SPOS system, which utilizes the minimum-time-en-route optimization only, fuel consumption is calculated according to the daily consumption rate programmed into the system by the user. Required average speed en-route, according to the required ETA, can only be calculated manually by the user.

In the Bon Voyage system, the user has two types of fuel optimization: least fuel and least fuel with fixed ETA. Fuel consumption is utilized by a declared daily consumption at NCR (Nominal Continuous Rate) and a standard, default, fuel-consumption curve, the same for all available in the system types of vessels (speed-down curves). The system does not offer the possibility to view the fuel curve nor to edit it.

System reports

In both systems, evaluation of the optimized route is done with the use of system reports. Their detailed list and comparison is presented in Table 2.

Table 2. Comparison of elements of a programmed route in system reports from SPOS and Bon Voyage [authors' findings based on references (Meteo Consult BV, 2009; Applied Weather Technologies, 2014)]

Compared item	SPOS (Route Info)	Bon Voyage (Voyage Details)
Waypoint, position,		
ETA AT waypoint	X	X
Course over ground	X	X
Type of navigation (great circle/rhumb line)		X
Distance between waypoints	X	X
Distance to go		X
Speed over ground	X	X
Calm sea speed	X	X
Type of weather data (forecast/climatic data)	X	
Wind (direction, velocity)	X	X
Significant waves $h_{1/3}$ (direction, height, period)		X
Swell (direction, height, period)	X	X
Seas	X	X
Surface current (direction, velocity)	X	X
Weather and current factor		X
Vessel icing		X
Ice pack and icebergs	X	X
M/E RPM		X
M/E indicated power		X
Daily fuel consumption		X
Average M/E RPM		X
Torque		X
M/E Power		X
Slip		X
Thrust		X
Thrust power		X

In the Bon Voyage system, the user can export the data from the table *Voyage Details* into MS Excel for further processing; there is no such option in the SPOS system.

In the SPOS system, an additional table of weather situations on a created route is available (*Comparison Wx*). It includes the following:

- Route name;
- Type of optimization;
- ETA;
- Average and maximum wind velocity en-route;
- Number of hours with wind velocity exceeding 34 kts;
- Average and maximum wave height;

- Number of hours en-route with wave height exceeding 4 m and 8 m; and
- Influence of the surface current on the speed over ground.

Conclusions

Both ocean-voyage planning and programming systems compared in this article, the SPOS system from the Meteo Consult Group and the Bon Voyage system from AWT, meet the requirements of shipping in terms of weather-navigation safety as stipulated in the respective chapters and rules of the SOLAS and STCW conventions. They can be used as a decision-making-support tool in the process of planning and programming of a ship's ocean route.

The approach to the optimization process in both systems is different and emphasis on route-programming process is placed differently in each system. Route-planning-and-programming tools in both systems seem to be designed for two different systems of ship operations. For the SPOS system, emphasis is placed on the navigational aspects of the voyage, weather navigation safety considerations, and achievement of the most-accurate navigational results when determining the minimal-time route. It has also been designed to solve the problem of time optimization of the voyage, and seems to be best suited to the needs of irregular, tramp shipping, in particular for ships under charter. Comparatively, the Bon Voyage system has priorities placed on the economical and operational issues of shipping and hence will find more applications in regular, liner trade.

Both systems are route-optimization tools using the isochrone method; however, there are significant differences in both systems in terms of weather information, file size, procedure of creating the route population, and their ranking in the aspect of navigation safety, limitations, and restrictions definition and route evaluation in system reports, etc.

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Navigation in emission control area zones

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Key words: ECA, exhaust emission, ship route optimization, fuel criterion, route programming, Bon Voyage

Abstract

The article presents the origin of Emission Control Area (ECA) zones, a timetable for their enforcement, criteria of their implementation and the principles and rules of navigation in these areas. Plans and areas of the next ECA zones envisaged for the future are presented. Least fuel route programming was presented, together with a description of safety rules during the change-over procedure in operations concerning the main engine and other ship systems. An attempt to identify the problems that may be encountered when programming the routes with the use of on-board routing systems, like Bon Voyage of AWT, leading through the ECA zones, has been made. Examples of such problems, taken from a true voyage of a postpanamx container vessel on a transpacific voyage, have been presented. A generalized algorithm for programming the route leading through the ECA zone according to the least fuel criterion has been presented.

Origin of ECA zones and their description

Navigation in ocean regions has recently been subjected to certain restrictions and constraints by coastal states. This was due to recently introduced means of emission control from ships, with respect to route choice, planning and programming. In Europe, this applies to the Baltic Sea and North Sea and is being implemented in the Mediterranean Sea and Black Sea. In the Pacific and Atlantic areas, it affects the coasts of the USA and Canada. Coastal states aspire to control and restrict emissions from ships.

Introduction of the *Emission Control Areas* (ECA) results from Annex VI of the MARPOL Convention. It regards various aspects of air pollution from ships, its limitation methods and means of control by the administration, surveys and certification of ships greater than 400 GT and having engine power higher than 130 kW. The regulation has been adopted by the IMO in 1997 and, after having been ratified by a sufficient number of member states, came into force on May 19th 2005. Its rules 13 and

14, regarding SO_x and NO_x emissions from ships, are of the greatest significance for shipping.

Annex VI of the MARPOL Convention determines that states, or groups of states, are the only bodies that can apply to IMO for the establishment of an ECA zone. Proposals have to be evaluated according to the following criteria (IMO, 1978):

- Geographical delineations of the ECA zone.
- A description of how the emissions from ships affect the land and sea region on a proposed ECA zone.
- A description of the hydrometeorological conditions in a proposed ECA zone.
- Sea traffic density in a proposed ECA zone.
- Means of control and execution of emission control and restriction.

Until now, 5 such ECA zones have been established. Their list and detailed description is presented in Table 1.

ECA zones in the Baltic Sea, North Sea and English Channel are presented in Figure 1, both North American ECA zones and planned ECA zones are shown on Figure 2.

Table 1. Currently existing ECA zones and dates of their adoption, introduction and enforcement. SO_x – control of sulphur emission, NO_x – control of nitrogen emission, PM – control of particulate matters emission [authors' findings based on (Raets Marine Insurance BV, 2013; Cullinane & Bergqvist, 2014; Lloyds's list, 2015; Maritime Cyprus, 2015; Ministry of Transport of People's Republic of China Website, 2016)]

ECA zone	Adoption	Introduction	Coming into force
Baltic Sea (SO _x)	26.09.1997	19.05.2005	19.05.2006
North Sea and English Channel (SO _x)	22.07.2005	22.11.2006	22.11.2007
North American ECA zone (SO _x , NO _x , PM)	26.03.2010	01.08.2011	01.08.2012
Caribbean ECA zone (SO _x , NO _x , PM)	26.07.2011	01.01.2013	01.01.2014
Pearl River, Yangtze River, Bohai RIM ECA zones (PRC) (SO _x)	01.01.2016	01.01.2016	01.01.2016



Figure 1. ECA zones in the Baltic Sea and in the North Sea (Maritime Cyprus, 2015)

In both European ECA zones, emission control applies for sulphur oxides only (SO_x), whereas in American zones emission control also covers nitrogen oxides (NO_x) and particulate matters (PM).

Other ECA zones are planned. Figure 2 shows the existing (areas marked green and blue) and planned (areas marked grey) ECA zones. Existing European,

North American, Hawaiian and Puerto Rican ECA zones and ECA zones planned for the future are marked.

Emission regulations in ECA zones

Annex VI of the MARPOL Convention as well as the local acts of law resulting therefrom (e.g. EU Directive 2012/33) regulate the permissible emission limits inside and outside of ECA zones.

Emission control is defined by the maximum allowable sulphur content in marine fuel oil. Annex VI of the MARPOL Convention determines the following limits and their introduction dates (Raets Marine Insurance BV, 2013):

1. Inside ECA zones:
 - Before 01.07.2010 – maximum allowable sulphur content in fuel oil – 1.5%.
 - After 01.07.2010 – maximum allowable sulphur content in fuel oil – 1.0%.
 - After 01.01.2015 – maximum allowable sulphur content in fuel oil – 0.1%.
2. Outside ECA zones:
 - Before 01.01.2012 – maximum allowable sulphur content in fuel oil – 4.5%.
 - After 01.01.2012 – maximum allowable sulphur content in fuel oil – 3.5%.

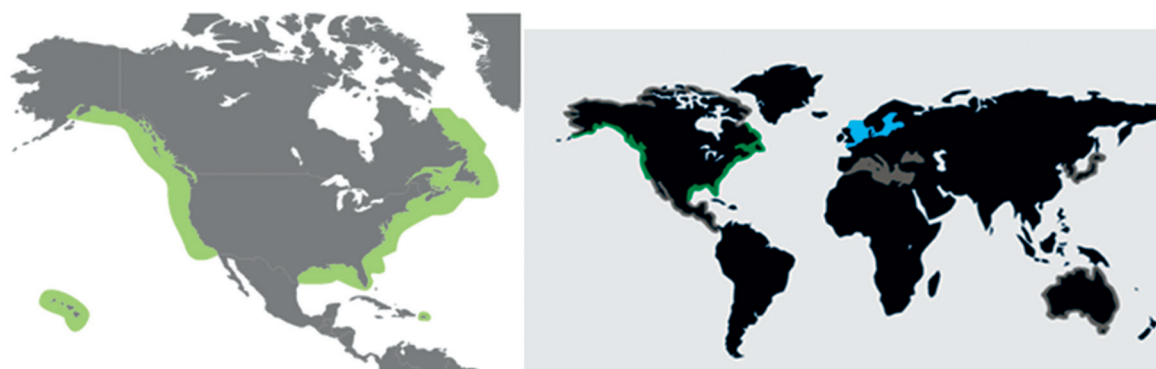


Figure 2. The North American, Hawaiian, Puerto Rican and other existing ECA zones and planned ECA zones (Maritime Cyprus, 2015; Lloyd, 2015)

- After 01.01.2020 – maximum allowable sulphur content in fuel oil – 0.5.

Introduction of the 0.5% limit as the maximum allowable sulphur content in fuel oil may be delayed until 01.01.2025, depending on an evaluation of the atmospheric pollution by a panel of independent experts under IMO supervision, planned for 2018. The information has been presented graphically in Figures 3 and 4 (Raets Marine Insurance BV, 2013).

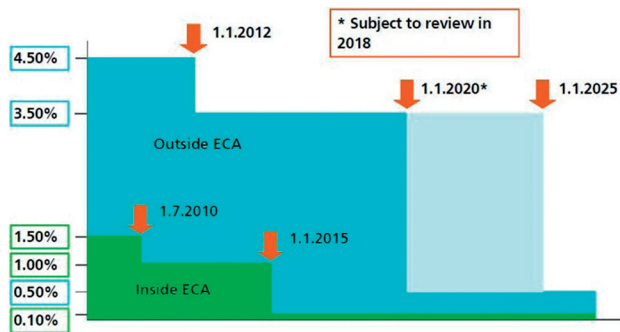


Figure 3. Maximum limits of sulphur content in marine fuels (vertical axis) and dates of their enforcement (horizontal axis) (Raets Marine Insurance BV, 2013)

The EU Directive 2012/33 will implement the 0.5% limit for the maximum allowable sulphur content in fuel oil used on ships navigating in waters under the jurisdiction of EU member states outside ECA zones, irrespectively of the IMO evaluations. For ships in transit only, not calling at EU ports, the limit on the maximum allowable sulphur content in fuel oil has been set to 1% o until 01.01.2020. Past that date, it will be decreased to 0.1% (Raets Marine Insurance BV, 2013).

Neither the MARPOL Convention nor the EU Directive 2012/33 impose any obligations to report fuel switchover times or positions on ships; however, the ships are obliged to carry and possess on-board

suitable and appropriate documentation, with which it is possible to prove, in case of control, the compliance with rules and regulations. This documentation should include:

- Bunker Delivery Notes that confirm compliance of bunkered oil with existing regulations and limits – provided by the bunker deliverer at bunkering;
- Bunker samples results – performed by a land laboratory;
- Written procedure of fuel switchover approved by a relevant administration;
- Records of fuel switchover in relevant documentation (Deck Log Book, Oil Record Book);
- Voyage plans marked with position of fuel switchover;
- Drawings of installations, valves and fuel pipelines;
- SEEMP (*Ship Energy Efficiency Management Plan*);
- EEDI (*Energy Efficiency Design Index*);
- *Cargo Ship Air Pollution Prevention Certificate (CSAPPC)*.

This documentation and records may be subjected to inspection by Port State Control. Coastal states can also monitor compliance with regulations by other means, e.g. monitoring from air or other methods.

Navigation in ECA zones and least fuel optimization

The above mentioned constraints are the source of certain problems in planning and programming routes passing through the ECA zones, according to the least fuel criterion. A mathematical formula dealing with this set of problems is relatively simple and is shown below:

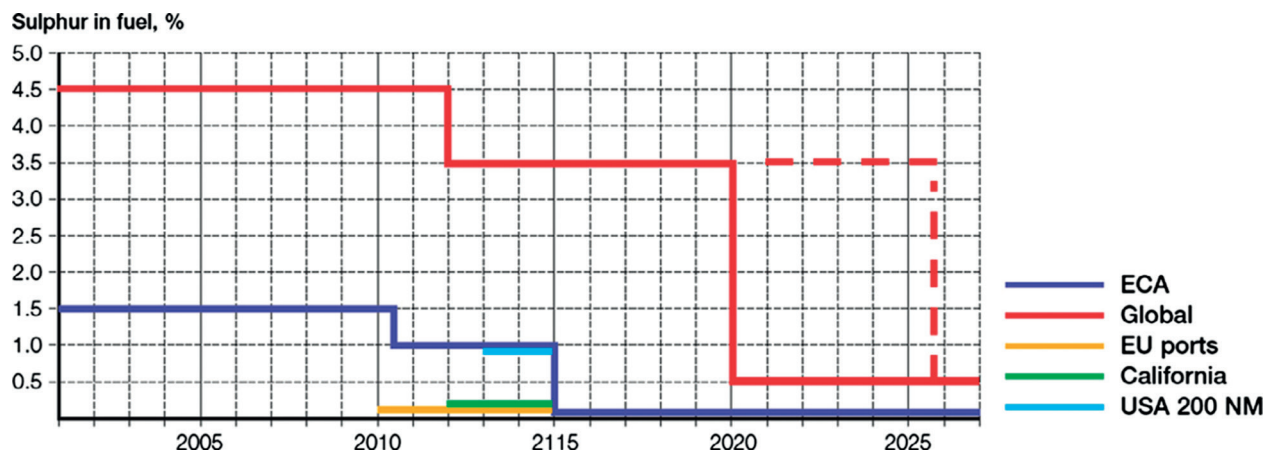


Figure 4. Development of the global and local regulations regarding sulphur emissions from ships (Cullinane & Berqvist, 2014)

$$K_{\text{Fuel}} = F_{\min} (K_{\text{Fuel}}(\text{ECA}) + K_{\text{Fuel}}(\text{Non-ECA})) \quad (1)$$

where:

K_{Fuel} – total fuel cost;

$K_{\text{Fuel}}(\text{ECA})$ – function describing the fuel costs inside the ECA zone;

$K_{\text{Fuel}}(\text{Non-ECA})$ – function describing the fuel costs outside the ECA zone.

In practice this set of problems has not been satisfactorily solved in weather optimization systems. It is best illustrated in an example below and in Figures 5 and 6.

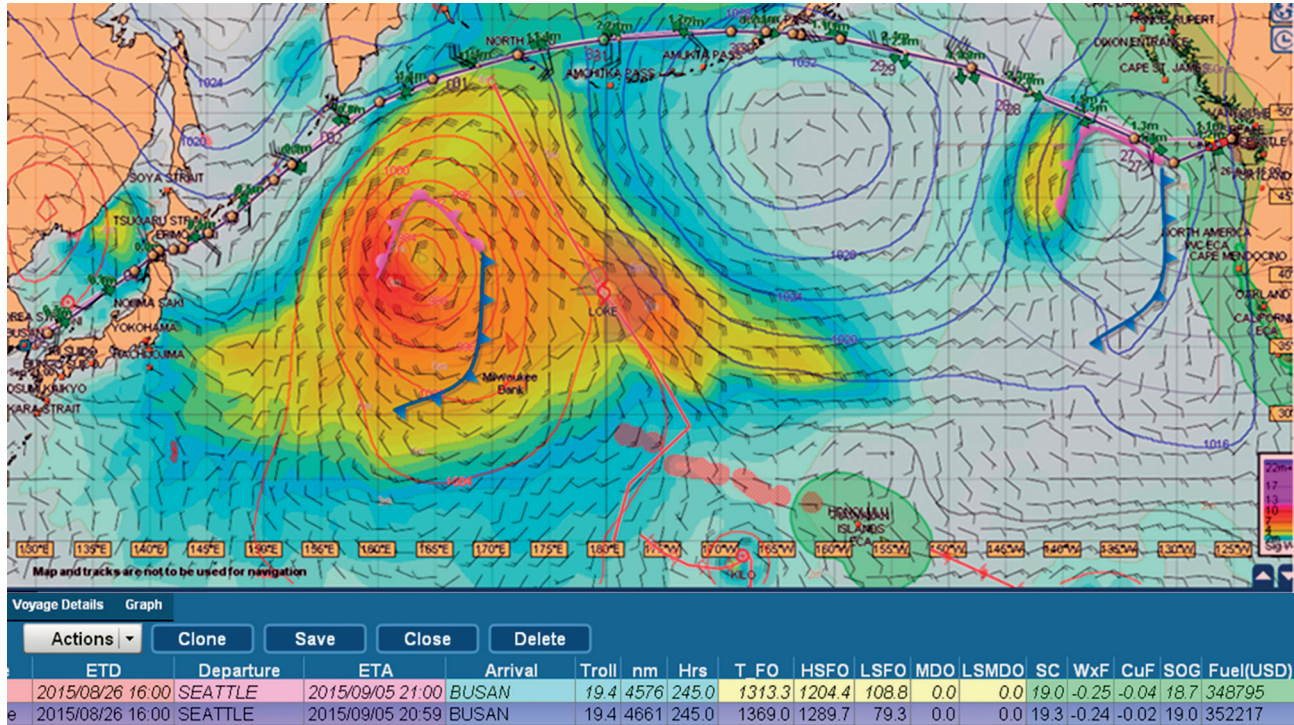


Figure 5. Voyage Seattle–Busan. Comparison of a least fuel with fixed ETA optimization (bold route on the chart, bottom line in the table) against the route programmed manually (thin route on the chart, upper line in the table)

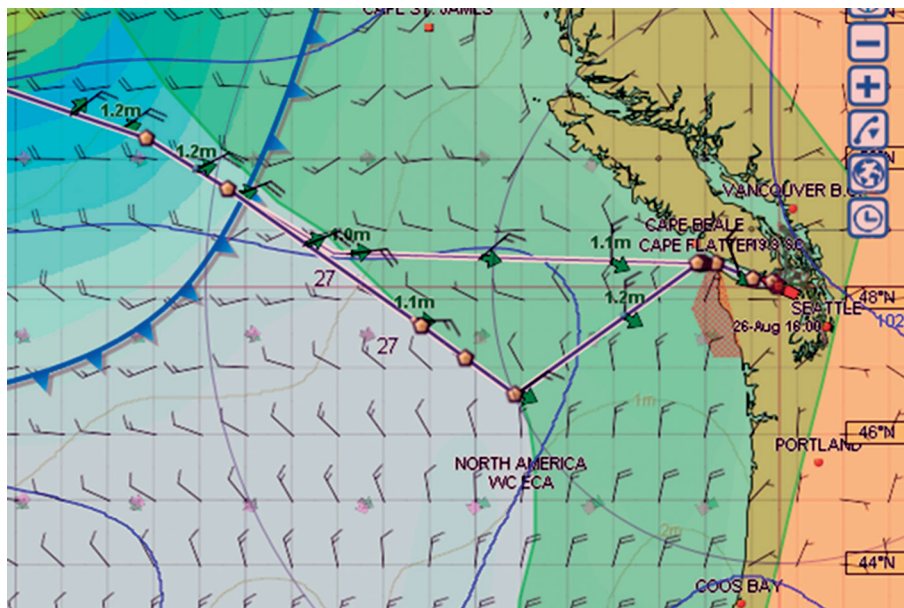


Figure 6. Voyage Seattle–Busan. Comparison of a least fuel with fixed ETA optimization (bold route on the chart, bottom line in the table) against the route programmed manually (thin route on the chart, upper line in the table) – A close up of the initial stage of both routes

Explanations for Figure 5:
 ETD – Estimated time of departure;
 Departure – Port or Point of the completion of the voyage;
 ETA – Estimated time of arrival;
 Arrival – Port or Point of the beginning of the voyage;
 Troll – Roll period;
 Nm – Nautical mile;
 Hrs – Total steaming time en route in hrs (voyage duration in hrs);
 TFO – Total fuel oil consumption en route;
 HFSO – High Sulphur Fuel Oil consumption en route;
 LSFO – Low Sulphur Fuel Oil consumption en route;
 MDO – Marine Diesel Oil consumption en route;
 LSMDO – Low Sulphur Marine Diesel Oil consumption en route;
 SC – Calm Sea Speed, ship's speed en route for calm seas, calculated according to the following formula:

$$SC = DTG/TTG - WxF - CuF$$

DTG – Distance To Go;
 TTG – Time To Go;
 WxF – Weather factor showing the influence of weather on speed over ground in knots;
 CuF – Current factor showing the influence of surface current on speed over ground in knots;
 SOG – Speed Over Ground;
 Fuel (USD) – Fuel cost en route;

The route created manually is better than the route created by BVS in terms of fuel consumption and voyage costs, by 56 tons of fuel and 3422 USD, respectively, despite the fact that the amount of low sulphur fuel oil consumed (inside the ECA zone) is greater by 29.8 tons. The above example shows unequivocally that the Bon Voyage System does not solve the fuel optimization problem satisfactorily.

The function describing the consumption of fuel inside the ECA zone is superior to the function describing the consumption of fuel outside the ECA zone. The priority in BVS is the minimal consumption inside the ECA zone, which is a mistaken assumption.

AWT, the maker of the system, is aware of this situation and recommends shore-based weather routing for all ships using the BV system. Voyage optimization of routes leading through ECA zones are given by AWT in the form of text recommendations worked out in the shore-based center by weather experts.

Conclusions

Coastal states and the IMO constantly aspire to control and restrict emissions from ships in their areas of jurisdiction. New ECA zones and ever-lower limits on sulphur, nitrogen and particulate matters content in marine fuel oil are being constantly implemented. This is a source of significant constraints and restrictions in the choice of routes available to ships and in planning and programming the vessel's route. Another problem is the correct mathematical solution of ocean route optimization according to the least fuel criterion of routes leading through the ECA zones in voyage optimization systems like the Bon Voyage system. Existing tools do not solve that task correctly and satisfactorily.

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Transportation Engineering

Tangible benefits of using liquefied natural gas fuel in the urban transport of Szczecin

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Key words: LNG fuel, exhaust emission, urban transport, Szczecin, alternative solution, costs

Abstract

Being the cleanest mine fuel due to the release of low exhaust emissions into the atmosphere, natural gas has been utilised by many fields of transport. A rapidly growing world market of liquefied natural gas (LNG) fuel has enabled to implement this fuel in urban transport. This article concentrates on presenting an alternative solution for the use of LNG fuel in urban buses to reduce exhaust emission using the example of Szczecin. On the basis of a significantly growing segment of the engines for the gas driven market, the article also shows the possible costs arising from the use of LNG fuel in urban buses of Szczecin. The impact to the natural environment from the use of diesel fuel from vehicles was analysed. Based on the exhaust emission analysis this article shows the difference between using a fuel which emits less noise and is a cleaner energy source with high energy efficiency and the fuel used by carriers.

Introduction

The steadily increasing trend in prices of fuel oil, the imposition of increasingly stringent emission regulations by the European Commission, the continuous growth of traffic and environmental aspirations pose serious problems with the use of conventional fuels such as diesel fuel or gasoline. These problems, are not of an economic nature, but relate to the continuous deterioration of air quality – a phenomenon mainly occurring in cities. One possible remedy is the use of liquefied natural gas (LNG) in the form of LNG fuel, which has a calorific value comparable to diesel fuel and gasoline, as well as better composition combustion, a lower price and in contrast to the CNG is easier to transport (Śliżak, 2013).

In the current situation of the petroleum fuel market, the technology has become increasingly common to allow vehicles to be powered with natural gas. Since the fifties, there has been about 2000 cars in Poland which used natural gas (PGNiG, 2014). The world's interest in natural gas as a motor fuel

intensified in the 70s during the oil crisis. It was caused by the scarcity of raw materials and the rapidly growing sector of transport vehicles. Currently, the use of natural gas has both economic and environmental dimensions.

LNG is one alternative fuel which has a limited impact on the environment. In contrast to gasoline or diesel fuel, in the event of a spill, LNG does not cause contamination of the environment, nor does it pollute waters or poison animals due to its quick evaporation into the atmosphere. Additionally, it does not compound with water. However, the main component – methane, is a strong greenhouse gas, 72 times stronger than carbon dioxide (on a 20 year scale) (Ramaswamy, 2001). The following table (Table 1) shows the components of LNG fuel.

An important argument for the use of LNG is that simultaneously to the condensation process, the gas is cleaned from water vapour, helium, nitrogen, carbon dioxide, propane-butane and partly from oxides of sulphur. Because of differences in condensing temperature of the natural gas components,

Table 1. Composition of LNG (based on data (PGNiG, 2014))

No.	Component	Content mass [%]
1	Nitrogen	≥ 4
2	The sum of combustible ingredients	≥ 96
3	Methane	≤ 93.83
4	Ethane	≤ 1.72
5	Propane	≤ 0.4
6	I-butane	≤ 0.03
7	N-butane	≤ 0.015
8	Pentane	≤ 0.005
9	Carbon dioxide	≤ 0.005
10	Water	≤ 0.0002
11	Sulphur compounds	≤ 0.0006
12	Mercury	≤ 0.001

the combustion products of LNG are mainly carbon oxides, water and small amounts of nitrogen oxides with very low particulate emission. For comparison, the combustion products of diesel fuel in internal combustion engines are compounds such as oxides of sulphur, carbon dioxide, carbon monoxide, nitrogen oxides, particulate matter and hydrocarbons, like aldehydes.

Another advantage of LNG fuel is its competitive price relative to diesel fuel and the fact that natural gas in a liquefied form occupies about 600 times less volume compared to normal conditions. Due to this feature, LNG can be transported over long ranges easily – with the only condition being the need to use special cryogenic tanks or cylinders, whose main feature is the ability to maintain a constant low temperature gas.

Calorific values of diesel fuel and natural gas are at a similar level. Given the differences in the combustion process and the generated heat (loss), fuel consumption in the case of LNG is higher. However, the current downward trends in prices of LNG – (with an average decrease in world prices of about 30% in the period from March 2014 to March 2015) (CIRE, 2016), it is a more economically profitable fuel.

Economic and ecological benefits arising from the use of LNG fuel in public transport in Szczecin

Roads and Transport Authority in its subordinate companies SPA “Dąbie” SPA “Klonowica” PKS Szczecin and SPPK have 77 bus routes and operate a total of 230 vehicles. The average age of rolling stock is different for each company, but the average

age of a Szczecin bus is nearly 11 years. The average number of kilometres travelled by bus is 235 km/day, thus every month gives about 7000 km and the annual result is 84,000 km/year. Taking the average value of combustion of 43 l/100 km, the average daily bus burns approx. 100 litres of diesel fuel per month giving a figure of around 3,000 litres. For a total bus fleet, over 1.6 million vehicle-kilometres will be covered while more than 692,000 gallons of diesel fuel will be burnt per month (ZDiTM, 2016).

From an economic point of view, the choice of LNG for urban transport is a profitable decision (Table 2). The cost per 100 kilometres for an urban bus in Szczecin, taking an average of combustion at 43 litres per 100 km is less than 170 PLN (diesel at a price equal to 3.94 PLN/l). To compare, declared fuel combustion of bus Solbus Solcity 12 powered by LNG is 51.6 Nm (36 kg) per 100 km (Krone, 2006), which shapes the cost at less than 108 PLN (the price of 3 PLN/kg). The difference in the cost of driving per hundred kilometres is as high as 36%. Continuing this line, ZDiTM buses annually overcome approx. 19.35 million vehicle-kilometres consuming 8.32 million litres of diesel fuel worth close to 32.8 million. LNG consumption amounts to around 7.3 million kg worth 21.9 million. This results in the formation of savings equal to about 10.9 million during the year.

Table 2. Properties and data spreadsheets for fuel for city buses

	LNG	Diesel
The calorific value	50 MJ/kg	42–44 MJ/kg
Equivalent energy	1 kg	1.23 kg
1 m ³	430 kg	820–845 kg
Listed price	6.9 \$/MMBtu*	355 \$/t**
Market price	3 PLN/kg	3.94 PLN/l***
Density	450 kg/m ³	840 kg/m ³
CO ₂ emissions	1 kg LNG is burned, creating 2.79 kg of CO ₂	1 kg diesel is burned, creating 2.64 kg of CO ₂

* The average trading price of LNG in Japan and in the UK in February 2016; equal 0.93 PLN/Nm³, 536 PLN/m³, 1.31 PLN/kg by the US dollar 3.74 PLN dated. 31.03.2016

** On the day 31.03.2016. For 1.13 PLN/l, acc. US dollar exchange rate 3.74 PLN.

*** Diesel price on the Polish market dated. 31.03.2016.

The use of LNG, unfortunately, brings some inconvenience. One example is the higher cost of the purchase of rolling stock. For vehicles with a length of 12 m, these costs are increased to about 200,000 PLN and for 18 m length can be as high as 430 thousand PLN (Table 3).

Table 3. List of the costs of buses in the basic version and runs on LNG/CNG (CBA, 2016)

Brand and model	Price + VAT [PLN] (basic version)	Price + VAT [PLN] (LNG/CNG)
Iribus Citelis 12	640,000	CNG/LNG 730,000
Iribus Citelis 18	820,000	CNG/LNG 950,000
MAN Lion's City	720,000	CNG/LNG 920,000
Mercedes-Benz Citaro	820,000	CNG 940,000
Mercedes-Benz Citaro G	1,300,000	CNG 1,700,000
Solaris Urbino 12	720,000	CNG 830,000
Solaris Urbino 15	800,000	CNG 870,000
Solaris Urbino 18	910,000	CNG 1,350,000

Assuming that an additional contribution to the purchase of a vehicle will reach 200 thousand PLN, after less than 4 years of use, it begins to generate additional profits (Table 4, Figure 1). Differential equation of fuel expenses with mileage 85,000 km/year (Śliżak, 2013):

$$\frac{s}{100}(p_1 \cdot q_2 - p_2 \cdot q_1) = x \quad (1)$$

where:

- s – the average annual mileage;
- p_1 – price of a litre of diesel fuel;
- q_1 – average fuel consumption of diesel fuel per 100 kilometres;
- p_2 – price per kilogram LNG;
- q_2 – average fuel consumption of LNG;
- x – the difference in operating costs.

$$\frac{85,000}{100} [\text{km}] \cdot \left(3.94 \left[\frac{\text{PLN}}{\text{l}} \right] \cdot 43 \left[\frac{\text{l}}{100 \text{ km}} \right] - 3 \left[\frac{\text{PLN}}{\text{kg}} \right] \cdot 36 \left[\frac{\text{kg}}{100 \text{ km}} \right] \right) \approx 52,200 [\text{PLN}]$$

Data calculation:

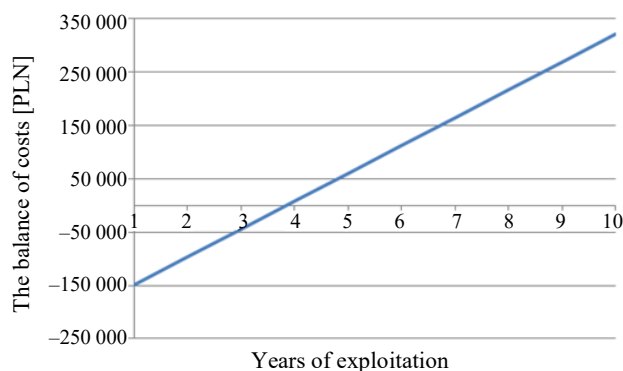
- mileage: 85,000 km/year;
- burning diesel: 43 l/100 km;
- burning LNG 36 kg/100 m;
- Diesel price: 3.94 PLN/l;
- LNG price: 3 PLN/kg.

One barrier preventing investment in liquefied natural gas power systems is the lack of infrastructure for refuelling. There are tanker trucks with the capability of refuelling other vehicles, but it is a cost-effective solution for only a small number of customers. Assuming, that Szczecin public transport companies do invest and develop an LNG-powered fleet, a solution would be needed in the form

Table 4. The balance of costs incurred and obtained with the introduction of LNG

Year of exploitation	Surcharge when buying bus [PLN]	The balance of costs [PLN]
	-200,000	
1	52,200	-147,800
2	52,200	-95,600
3	52,200	-43,400
4	52,200	8,800
5	52,200	61,000
6	52,200	113,200
7	52,200	165,400
8	52,200	217,600
9	52,200	269,800
10	52,200	322,000

of stationary fuel station. This involves the filling station having in its offer traditional fuels, and additional fuels LNG and CNG. The occurrence of such stations would be a positive asset for Szczecin because of the inclusion of the city to the Blue Route (ang. *Blue Corridor*). Blue Trail is the idea of creating a network of routes with LNG/CNG stations in Europe, mainly for trucks. The cost of building LNG stations with a capacity of 12 vehicles per hour is approx. 750 thousand € (Śliżak, 2013).

**Figure 1. The period of reimbursement of additional expenditure on the purchase of LNG bus (based on data from Table 4)**

Buses have a standard LNG tank with a capacity of 330 dm³, which can contain about 130 kg of fuel. This does not mean that they are the only possible capacity to install. This volume is comparable to the volume of the standard diesel tank. Buses burning 36 kg/100 km of LNG are able to travel about 350 km on a single tank. Taking into account the characteristics of connections, most buses on Szczecin bus lines, where the average daily length of the route is 235 km, could complete their route on a single tank.

From an environmental point of view, the use of LNG as a fuel is much more advantageous than the use of oil. The reason for this is much smaller and less harmful emissions of fuel combustion products (Table 5).

Table 5. European emission standards for diesel engines of trucks and emissions LNG [g/kWh] (based on Michalowski, 2007; DieselNet, 2016)

Level	CO	HC	NO _x	PM
Euro I	4.5	1.1	8	0.612
	4.5	1.1	8	0.36
Euro II	4	1.1	7	0.25
Euro III	2.1	0.66	5	0.1
Euro IV	1.5	0.46	3.5	0.02
Euro V	1.5	0.46	2	0.02
Euro VI	1.5	0.13	0.4	0.01
Natural gas	0.12	0	0.36	0.007

For LNG fuel, lower rates per kilowatt hour of fuel burned is observed compared to the most restrictive standard Euro VI for diesel. For carbon monoxide it is lower by 92%, and the emission of hydrocarbons has been almost completely eliminated. Emissions of nitrogen oxides and particulate matter is smaller by 10% and 30% respectively. For the Euro IV standard, which is used by most of Szczecin buses, the situation is as follows: 92%, 100% (a small part), 90% and 65%. Current CO₂ emissions from Szczecin bus is around 21,900 tonnes, while with the use of LNG, it would be reduced by 7.5% to 20.3 thousand tonnes.

Often overlooked a kind of “pollution” of the environment is noise. It also adversely affects physical and mental health, however by using LNG fuel, noise is significantly reduced compared to a conventional diesel engine (Table 6).

Table 6. Noise reduction in Scania trucks (Wodolazski, Rejman-Burzyńska & Jędrzyk, 2013)

Distance	Diesel fuel	Methane	Difference
	dB(A)		
7.5 m forward	71.7	60.6	-10.5
7.5 m from left side	69.6	59.8	-9.8
7.5 m from right side	69.6	60	-9.6
Cabin (driver's ear)	60.6	54.7	-5.7

The differences in noise levels range from 5.7 to 10.5 dB (A), and it should be noted that decibels are on a logarithmic scale. This means that a difference of 10.5 dB in the human mind is considerable and

the difference between LNG engines and diesel may be as high as 50%.

Installation of LNG fuel in vehicles and security

Technology in the construction of LNG vehicles guarantees safety. In addition to the specific multi-layer construction of the cylinder for liquefied natural gas (Figure 2), it has many different types of safety valves which function to regulate the transmission of gas inside the installation and the adjustment of pressure (Figure 3).

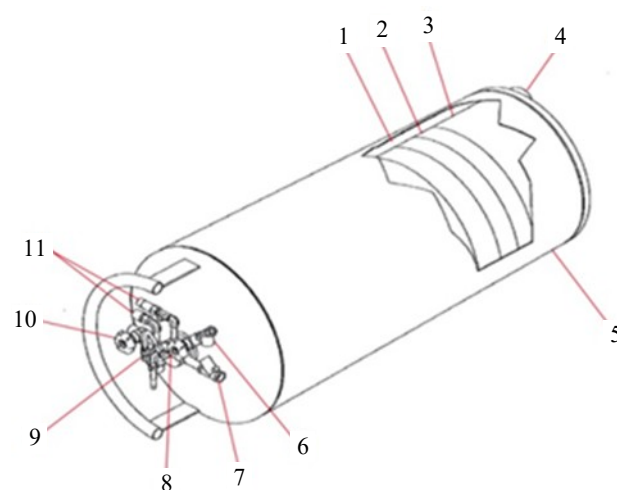


Figure 2. Schematic diagram of the LNG tank (Przegląd pożarniczy, 2016); 1 – vacuum space, 2 – isolating material, 3 – inner tank, 4 – underpressure valve, 5 – outer cover, 6 – outflow securing valve, 7 – bunkering securing valve, 8 – cutting off the fuel valve, 9 – tank pressure regulator, 10 – ventilation valve, 11 – safety valves

Tanks for the storage of LNG vary significantly from those used for CNG or LPG. The most important difference that distinguishes this type of tank is its thermal insulation, which is placed between the outer layer and inner vacuum tank. This is the best known radiant heat insulator so far. A good thermal isolation tank is needed to maintain the low temperature inside the tanks for as long as possible, which should be held at about -162°C . This ensures maintenance of the natural gas in liquid form and consequently, a reduced pressure ranging between 3 and 8.5 bar, for up to seven days.

Except for the vacuum space, the tank is composed from additional isolating material and an inner and outer tank. The inner tank is designed to keep the liquefied natural gas in a hermetically sealed environment, while the external tank with its thick,

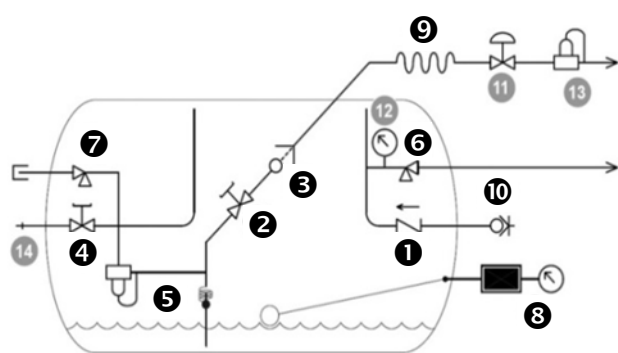


Figure 3. Scheme of the LNG fuel system (Przegląd pożarniczy, 2016)

reinforced walls protects the interior of the cylinder, mainly from mechanical shock and high temperatures (e.g. due. fire).

At the entrance to the tank, the installation is composed mainly of pressure regulators and valves. They ensure safe refuelling of LNG.

Safety valve refuelling (1), aims to prevent gas reversing to the power cylinder; the manual fuel shut off valve (2) is closed during repair and renovation work on the vehicle; the unduly valve (3) shuts off the flow of gas from the tank to the heat exchanger for excessive, uncontrolled discharge thereof; i.e. the ventilation valve (4) is used to drain the tank and for aeration during the first filling or when the tank has too large an amount of gas in the form of volatile a pressure regulator (5) in the vessel allows the vapour to be sent to an installation supplying gas to run the engine in the case where the pressure within the tank rises above the nominal allowable pressure (0.85 MPa); the main safety valve (6) vents gas at the moment when the pressure inside the tank exceeds 1.5 MPa to a special wire led out beyond the contour of the vehicle; the additional safety valve (7) is turned after exceeding a pressure of 2.25 MPa to quickly reduce high pressure in the tank; a heat exchanger to heat the LNG has this purpose so that the resulting vapour, can then go to the engine of the vehicle. Heat is obtained mainly by the engine refrigerating fluid. In order to fill the tank, the filling adapter (10) is needed. The automatic fuel shut off valve (11) blocks the flow of gas to the engine when the engine is switched off or when its turnover falls dangerously low. The supply pressure regulator regulates the pressure of the gas, where its value in the engine should be 0.67 MPa (Przegląd pożarniczy, 2016).

An important aspect for the safety of the LNG compared to other fuels (in particular diesel fuel) is its very low carcinogenicity. Virtually no solid particles

result from the combustion of natural gas and hydrocarbon NMHC, providing a cleaner exhaust gas (without soot and smoke emanating from the exhaust of the vehicle) and also a reduction in the incidence of cancer. Particulates generated during combustion of petroleum fuels have such a small size, that they are able to not only get to the human respiratory system, but also into the bloodstream (where they are impossible to remove from the body, allowing them to accumulate).

According to the World Health Organization (WHO) particulate matter (PM) shortens the life of the average person by about 8 months and specifically in Poland by 10.7 months.

Hydrocarbons are able to react with oxygen to form nitrogen peroxide, and various kinds of aldehydes and peroxides. Some of these have a narcotic effect, and are even fatal in high concentrations, while others combine with fats and accumulate in the human body acting as a carcinogen.

Other products of combustion are nitrogen oxides for example. Eliminated by the combustion of LNG are the more toxic products exhaust elements of diesel fuel. Nitric oxide is bound to haemoglobin, and is oxidized to nitrogen dioxide. The effects of poisoning are numbness of the limbs and the general weakness of the body. Carbon monoxide combines with haemoglobin much more simply than oxygen, which displaces it from the body. This results in body hypoxia, pulmonary enema and brain lesions, and at higher doses, can lead to death.

Conclusions

Implementation of an LNG power supply system in Szczecin transport would bring considerable economic benefits in the form of savings when buying fuel at 10.9 million dollars per year. This represents 36% of current expenditure on the purchase of diesel fuel. In addition, it would allow a reduction of noise and emissions in Szczecin; furthermore the construction of LNG filling stations would raise the prestige of the Szczecin city and include it into the Blue Corridors programme.

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A new concept for utilising the Oder waterway in intermodal container transport

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Key words: Oder waterway, container transport, river-land combined transport, profitability of transport, multilayer container transport, River – Class parameters, vertical clearance of bridges

Abstract

The article addresses the issue of the transport of goods on the Oder Waterway (Odrzańska Droga Wodna, ODW), in terms of its usefulness for the transport of containers in the face of limitations arising from the hydro-technical conditions of the river and the modernisation programme. A realistic estimate leads to the conclusion that by 2030 the CEMT Class III classification may be achieved in the upper and middle sections. Combined river and land transport of containers has been proposed as an applicable solution, considering the present condition and the predicted development and modernisation of the waterway within the next years. The main feature of this transportation concept is the principle of transporting multiple layers of containers on inland ships, reducing the cost of transport of individual containers. Sections of the ODW that meet the parameters of the CEMT Class III, or higher, will be used in such a way. In points of contact with sections that do not meet those parameters, loading points will be organised where the upper layers of containers will be removed from the barge and transferred either to land transport or a loading barge capable of going under low bridges.

The article presents analysis of the effect of the main parameters of the river and land system of container transport on its economic effectiveness. Those parameters are: the number of layers of containers on a barge, percentage of the entire route covered by land transport means, number and time of transshipments, and speed relations. Relationships between these parameters have been established, together with the principles of their selection, assuming the main criterion to be gaining profit by using combined transport in comparison with land transport. Examples of combined transport have been presented on the Gliwice–Świnoujście and Gliwice–Hamburg routes, including progress in modernizing the Middle Oder.

Introduction

The issue of how to use the Oder Waterway (Odrzańska Droga Wodna, ODW) is still of interest (Restel & Skupień, 2011). The current state may only be characterised as highly unsatisfactory due to the failure to take advantage of certain features, such as the lowest transport and carriage costs compared to all other modes of transport. A report issued by the Supreme Audit Office (Supreme Audit Office, 2014) puts it rather bluntly by pointing to the marginal significance of inland water transport in state transport and financial policies. However,

the financial plans that have been developed for the years 2014–2020 allow to determine that the real modernisation of inland waterways will happen in the 2030 perspective.

The ODW remains the only waterway in Poland which is at least partly prepared to serve as an international waterway. The middle, free flowing, section of the Oder presents the biggest hydrological problems. Works begun with the Program Dla Odry 2006, with the intent of reaching Class III parameters along the entire length of the waterway, are being carried out with delays (Kulczyk & Skupień, 2010). The immediate consequence is the loss of funds (Priority

VII of the Operational Programme ‘Infrastructure and Environment’). A published assessment of the current situation points to the unprofitability of the undertakings required to achieve Class IV (Fundacja im. Micheala Otto, 2010). In addition, the necessary restructuring of road and rail bridges increases the costs to the point that it is not possible to predict the time required for completing the project. Moreover, these costs have yet to be adequately estimated (Kulczyk & Skupień, 2010). Lately there has been improvement in matters of planning finances (Priority VII) and implementing the modernisation. Stage I (until 2020) aims at achieving Class III parameters on the Brzeg Dolny–Bytom Odrzański section, Stage II (2030 perspective) is going to improve the rest of the middle Oder. A realistic estimate leads to the conclusion that by the 2030 Class III parameters will be achieved only in the upper and middle sections. The modernisation of the border Oder, which has just begun, shall, in the nearest future, improve Szczecin’s connection with canals connecting the Oder with European inland waterways.

The range of cargo transported along the ODW is limited to dry bulk cargo (mainly coal and other mining products) (ECORYS, 2011; Fundacja im. Micheala Otto, 2010; Gawłowski, 2012; Niebieska Księga, 2002) and, periodically, oversized cargo. Container transport along the ODW is virtually inexistent, even though the cost of such transport would be 2.5 times lower than railroad transport and ca. 4 times lower than road transport.

The demand for supplying (and reclaiming) containers for the ports in the estuary region of the Oder is currently growing. The OT Logistics company requires a quick, quantitative development of reloading (next year it is hoping to achieve a reloading capacity of 200,000 containers per year). The limitations of the depth of the Szczecin port shipping lane will no longer exclude this port as works aimed at deepening the shipping route to 12.5 m have begun this year. The limitations to inland navigation arising from weather conditions on the Szczecin Lagoon should be viewed as a challenge in the implementation of sea and inland ships. The conditions which would allow inland container transport to the West coast are being established.

It has been estimated (Niebieska Księga, 2002) that the current condition of the middle Oder and the insufficient vertical clearance of some bridges eliminate the possibility to transport more than one layer of containers, whereas water transport should naturally allow transport of multilayer containers, further reducing the cost of transport of an individual

container. Yet, should we wait another century to reach conditions allowing for cheap mass container transport on the ODW? The solution seems to be combined land and water transport (Piechociński, 2007).

A new look at the issue of container transport on the ODW

The state of affairs outlined above seems to justify our concept that modernisation works on the ODW aiming at achieving Class IV (Supreme Audit Office, 2014) on its entire length in the foreseeable future are unreal. Therefore, we propose the combined method of land and water transport as feasible in view of the modernisation works envisaged for the next few years.

The main feature of this concept is the transportation of multiple layers of containers on inland ships, which would lower the cost of transport of individual containers. Those sections of the ODW which meet the parameters of Class III and higher will be used for this purpose. In points of contact with sections which do not meet these parameters, loading points will be organised (Figure 1, item 1), where the upper layers of containers will be removed from barges and transferred to means of land transport (Figure 1, item 2). The barges would proceed with one layer of containers only (item 3) until navigational conditions would allow to continue the cruise with multilayer cargo. In such a place a return loading of the upper layers to the barges would be performed (item 4).

By using a loading barge (Figure 1, item 5) equipped with a reloading device, it would be possible to bypass low bridges using road transport. Such a barge may remove the upper layers of containers and arrange them on its deck in one layer. Then the barge would go under the bridge (Figure 1, item 6)



Figure 1. A concept of combined multilayer container transport on the ODW

and, having passed it, return the containers to the transport barges as their upper layers (item 7).

Such a system may be imagined as consisting of a few bypasses of low bridges and a few road bypasses on the entire middle Oder, or parts of it, taking into account the current progress of modernisation. Some of the bridges may be grouped together and in the section from Brzeg Dolny to the mouth of the Warta River one may bypass only the parts of the river that are shallow (there are apparently a few of them) or present significant meandering. Certainly, one should seek an optimum solution cost-wise but also in view of other factors, such as the number of navigable days in a year (ice, floods) and the sociological impact of the project.

Data gathered by us suggest that such an option has never been considered. There have been, however, attempts to solve the problem of coal transport by combining river and railroad transport (Piechockiński, 2007).

An example of the scope of bypasses, which takes into account the scheduled modernisation of the middle Oder to the parameters of Class III, is shown in Figure 2. This modernisation will allow two-layer container transport on the new type INBAT barges (Figure 3) with a draft of 1.6 m. A convoy of two barges with an INBAT pusher may transport 84 containers at a time.

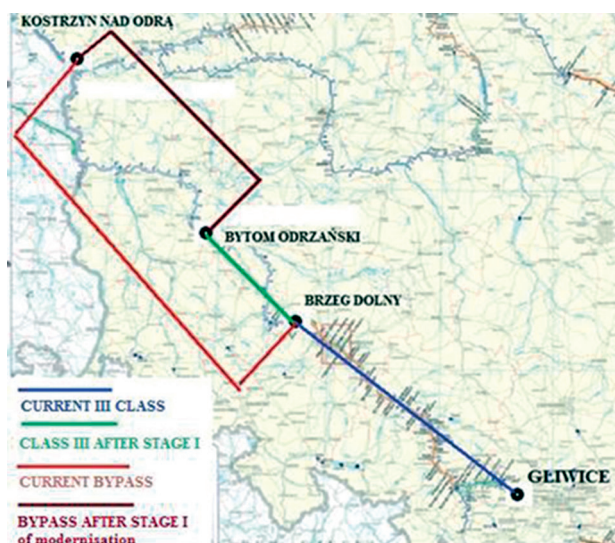


Figure 2. The scope of bypasses dependent on the progress of modernisation

The advantages of the proposed system are as follows:

- 1) large transport capacity (one water convoy takes twice as many containers as one train and the mean speed on land transport networks increases);



Figure 3. An INBAT barge may take 21 containers in one layer

- 2) low transport costs (benefit for the client) and low external costs (benefit for the carrier and the state);
- 3) flexibility (adaptation to the current condition of the ODW: the condition of the river channel, structures, ice, floods);
- 4) graduality (adaptation to the current progress of modernisation – implementation at the existing state of the ODW, fleet and ports);
- 5) patency of the ODW (possibility of using sections of international classes, including European waterways in the East-West and North-South systems);
- 6) stimulation of the growth and construction of inland fleet (the use of bankrupt shipyards, new solutions – especially for containers);
- 7) stimulation of the growth of ports and logistics centres (use of existing ones, e.g. Gliwice, Brzeg Dolny, Szczecin and the construction of new ones, e.g. Kostrzyn).

The specification of the main parameters of the system (percentage of land transport, number of transshipment points) ensuring its profitability is the subject matter of another academic paper (Hann, Piotrowski & Woś, 2014) and of an application to the National Centre for Applied Research to finance a project entitled “Combined Transport as a Basis for Effective Carriage of Containers by Oder Waterway in the Presence of its Limited Capacity”.

Profitability Estimation

In order to assess the practical usefulness of this proposal, a preliminary assessment was performed concerning the profit that could be achieved by its implementation without waiting for change in the classification of ODW. The transport of one layer of containers on the entire length of the ODW has

been adopted as a reference system (for example Gliwice–Świnoujście i.e. 744 km).

The choice of this reference has been made since the transportation of such a load along the ODW is currently considered admissible (Niebieska Księga, 2002). In particular, it is assumed that an insufficient clearance under bridges impedes the crossing with two layers of containers. This point of view has been questioned as the transport with two layers of containers from Szczecin to Koźle has occurred (Supreme Audit Office, 2014).

In practice, the vessel's draft (the state of loading and ballasting) and the water level are of importance as much as the height of the span. These are fortuitous conditions, whose assessment has not been made. Table 1 presents the parameters that determine the possibility of barge OBP500 to pass under the bridge. The following parameters are reported:

$H_{1,3}$ – Highest water level enabling passage under the bridge at a draught of 1.3 m;

$H_{1,7}$ – Highest water level enabling passage under the bridge at a draught of 1.7 m.

On the basis of these parameters, we can expect that the conditions causing a collision with the bridge during the transportation of two layers of containers may occur. Another question concerns the probability of such an event. The assumptions made regarding the construction of special barges equipped with ballast systems should also be specified.

The following have been assumed as the fundamental parameters of the system of combined transport (Hann, Piotrowski & Woś, 2014):

- the entire length of the transport river way, L_0 (e.g. distance from Gliwice to Świnoujście);
- the percentage, p , of land transport with respect to the entire length L_0 :

$$p = L_L / L_0 \quad (1)$$

- number of transshipments n , each including transshipment from a barge to another means of bypass transport and vice versa, along with necessary inter-operational storage;

- the number of container layers, w , transported by water.

The preliminary profitability assessment has been based on the comparison between the cost, K_0 , of transport of one container through the combined system on the entire route of the inland waterway, and using only the waterway along its entire length with the one-layer system.

The assumed system of reference is therefore the transport of one layer of containers along the entire route of the Oder Waterway (ODW; e.g. Gliwice–Świnoujście, i.e. 744 km). This is due to the fact that such transport is deemed possible with the current state of the ODW.

The cost of transport of one container (TEU) per one kilometre of the inland waterway has been assumed as the basic parameter. The following ratio has been accepted for the analysis as a comparative parameter:

$$\psi = \frac{K_0}{K_1} \quad (2)$$

where:

K_1 – cost of transport on the ODW of one container in one-layer system per 1 km of the river way;

K_0 – cost of transport of one container in the combined w -layered system per 1 km of the river way.

The cost of the combined transport consists of the following:

$$K_o = K_1 \cdot p + K_w(1-p) + K_L + K_p \quad (3)$$

where: K_w – cost of transport only by waterway of one container in the w -layered system per 1 km of the river way.

Table 1. Parameters determining the possibility of passing under the bridge for barge OBP500

Sections of the ODW	Localisation of bridge	km ODW	Clearance at WWŻ [cm]	WWŻ [cm]	$H_{1,3}$ [cm]	$H_{1,7}$ [cm]
Sewered the Odra River	Opole – railway bridge – road bridge	151.25	384	400	378	WWŻ
		151.25	370	400	348	387
	Brzeg	199.001	375	380	333	372
	Oława	216.42	370	550	498	517/537
	Ratowice	228.0	390	550	528	WWŻ
Brzeg Dolny – mouth of the Nysa Łużycka River	Głogów	393.3	390	485	453	WWŻ
	Nowa Sól	437.7	398	480	456	WWŻ
	Cigacice	470.7	372	460	410	429/449
	Nietków	490.5	379	420	377	386/416
	Krosno Odrzańskie	514.0	315	420	313	351/371
Mouth of the Nysa Łużycka River – mouth of the Warta River	Kostrzyn	615.1	367	535	480	519

Assuming that transport cost does not depend on the extent to which the barge is loaded:

$$K_w = \frac{1}{w} \cdot K_1 \quad (4)$$

K_L – the unit cost (per 1 km of the overland route) of land transport of one container per 1 km of the river way;

K_p – cost of transhipments of one container from a barge to land vehicle/train and vice versa, along with necessary inter-operational storage, per 1 km of the river way.

By defining the ratio of the rail or road transport cost to the cost of water transport in one layer:

$$\Psi_E = \frac{K_L}{K_1} \quad (5)$$

one may calculate the limit of the percentage of the land transport, p_E , with a given number n of transhipments with the criterion that:

$$\Psi \leq \Psi_E \quad (6)$$

In order for the combined transport to be profitable, one must assume that the percentage of the land transport shall be lower than the limit:

$$p = \eta \cdot p_E \dots \eta \leq 1 \quad (7)$$

The profit of transporting one container by combined transport in comparison with land transport is given by:

$$Z_0 = K_L - K_0 = K_1(\Psi_L - \Psi) \quad (8)$$

One may then determine a profit ratio as the percentage of the cost of river transport of one container in one layer:

$$z_1 = Z_0 / K_1 = \Psi_L - \Psi \quad (9)$$

Two general variants of land transport have been analysed:

G1 – land transport of all containers (no river transport on sections under Class III),

G2 – land transport of containers over the first layer and river transport of the one remaining level along river sections under Class III.

The advantage of the G2 variant is clear, as well as the significance of the number of transhipments.

The results of calculations presented below have been obtained after the following figures were estimated:

1. The cost of inland water transport of one container of the average weight of 16 t in one layer (assuming 20 containers per layer) amounts to $K_1 = 512 \text{ zł}/L_0$;

2. The cost of transport of one container by railroad: $K_L = 2.5 \text{ zł}/\text{km}/L_0$;

3. The cost of transhipment of one container: $K_p = 400 \text{ zł}/L_0$;

4. The duration of break caused by the transhipment of upper layers of containers: $T_p = 24$ hours.

Figures 4–6 present charts showing the limit value of the percentage of the land transport in the entire transport route depending on the number of transhipments. In order for combined transport to be profitable, i.e. meet condition (6), one should consider the p values above the curve. Negative figures point to the scope of inadmissible parameters. The chart in Figure 6 proves that, with 2 layers of containers, up to 8 transhipments are possible in order to achieve minimum profit. The chart in Figure 5 presents the connection between the profit ratio and the number of transhipments, calculated for $\eta = 0.66$.

The transport capacity has significant effect on the overall economic outcome. Combined transport is faster than river transport as part of the way “ p ” is covered with the speed of land transport, v_L . At the same time, the multilayer water transport must be adapted to the transport capacity of the land transport, e.g. in multi-carriage trains. The principle of

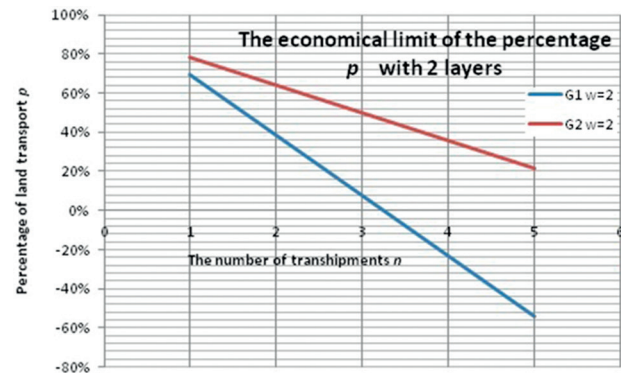


Figure 4. Dependence of the percentage of land transport on the number of transhipments and layers for two general variants of land transport. G1 and G2

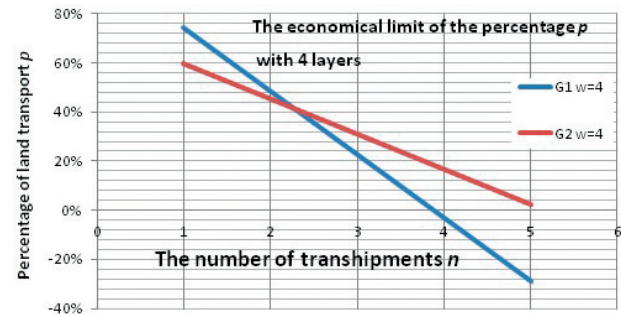


Figure 5. Dependence of the percentage of land transport on the number of transhipments and layers for two general variants of land transport, G1 and G2

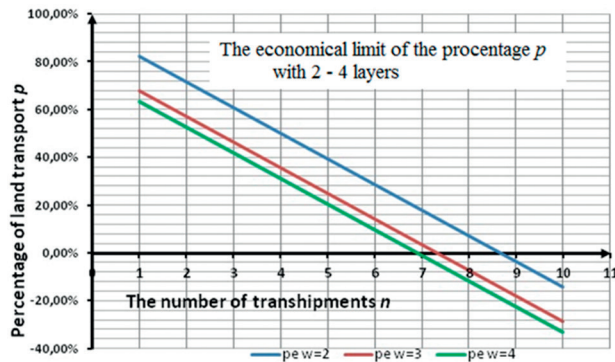


Figure 6. Influence of the number of transshipments and layers on the percentage, p , of land transport

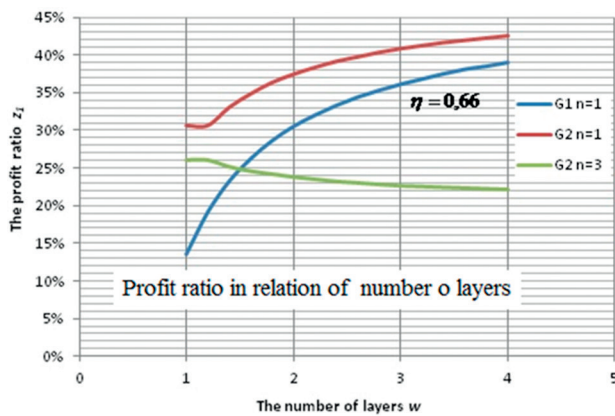


Figure 7. Dependence of the profit ratio on the number of transshipments, n , and layers, w , for two general variants of land transport, G1 and G2

combination may be the adaptation of the delivery time to transshipment and reception without storage, taking into account the lock capacity. The result will be a transport capacity higher than that of water transport in one layer. Such a state will multiply the profit as a result of the combination of water transport in a few layers with fast, multi-carriage railroad transport, in comparison with the results shown in Figure 5. The dependence of the equivalent velocity for the entire land and water route on the component velocities is set out by the following equation:

$$v_z = \frac{v_w}{1 - p(1 - \gamma) + n \cdot \delta} \quad (10)$$

where:

$\gamma = v_w / v_L$ – ratio of water transport velocity to land transport velocity;

$\delta = T_p / T_w$ – ratio of the duration of the storage break to the time of water transport on the entire route.

The transport capacity of the system is proportional to the number of layers, w . The ratio of

increasing transport capacity by using w layers in comparison to the one-layer transport may therefore be described as:

$$\beta = \frac{v_z}{v_w} \cdot w = \frac{w}{[1 - p(1 - \gamma) + n \cdot \delta]} \quad (11)$$

The demonstration of transport capacity ratio dependence on the main system parameters is presented in Figure 6. As one can see, even with a low (a few percentage points) share of land transport and six transshipments, one may increase transport capacity by as much as 50% in comparison to one-layer transport.

Profit per unit (per one container) obtained in combined transport with the equivalent velocity (10) in comparison to the land transport, as the percentage of the cost of one-layer river transport, is:

$$z = \beta \cdot z_1 \quad (12)$$

In practice, the frequency of deliveries is of great importance and it depends not only on the transport velocity but mainly on the logistics. Intermodal transport rises in Poland to the level of 6–8 trains per week. The combined water and land transport will be limited by the times of lockage and transshipment points as well as waiting at the locks and in transshipment points. While it is not limited much by timetables and the access to transport way, it is obstructed by navigation conditions. It is predicted that it will be possible to achieve the frequency of deliveries of about 30–40 barges per week in the navigational season. With a similar figure (40 containers) for each delivery in the land and combined transport, one may reinforce the profit.

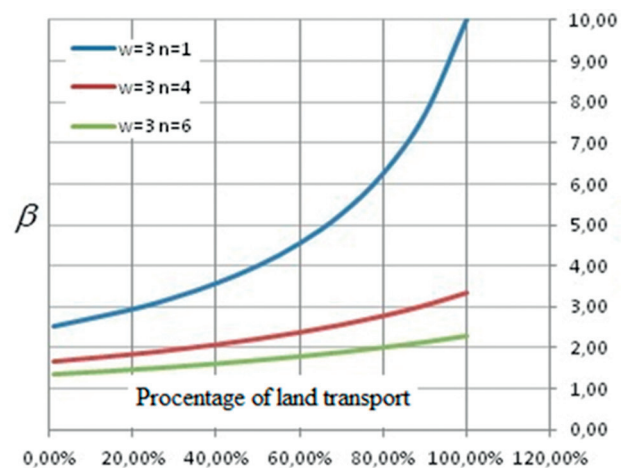


Figure 8. Example of transport capacity ratio

By $w = 3$, $\gamma = 0.1$, $p = 0.18 \cdot 0.66 = 0.12$, $n = 4$, $\delta = 0.2$, $\beta = 3$. This means that in the variant G2,

Table 2. Results of the analysis

Example	Number of Layers w	Number of Transshipments	Land transport %		Profit ratio z_1	β	Individual profit z
			Limit p_E	Done p			
	–	–	%	%	%	–	%
Variant IA: Gliwice–Świnoujście now	3	4	40	36	26	2.1	54
Variant IB: Gliwice–Świnoujście after stage I of modernisation	3	4	40	21	54	1.9	102
Variant IIA: Gliwice–Hamburg now	3	4	40	29	39	2.0	78
Variant IIB: Gliwice–Hamburg after stage I of modernisation	3	4	40	17	62	1.8	112

with 3 container layers, 4 transshipment operations and a 12% participation of land transport, the profit connected with the transport of 1 container may amount to about 66% of the water transport charges of this container in a single layer.

The capacity of land transport, ZPL, which may be defined as the quantity of trains used in 24 hrs and the quantity of wagons per train, must be adjusted to the transport capacity of the combined system, ZPK. This idea may be expressed through the following equation:

$$ZPL = ZPK = \beta \cdot \frac{v_w}{a} \cdot W_D \quad (13)$$

and:

W_D – quantity of layers transported by barges every 24 hrs;

a – distance between barges (assumed as a constant on the whole route).

In order to assess possible profits for the buyer of services, two examples of using the proposed system have been analysed:

Variant 1: Gliwice–Świnoujście route

- Now – 3-layer transport (60 containers) to Brzeg Dolny (including bypass of 3 bridges), unloading upper layers and bypass to Kostrzyn, loading upper layers and transport to Świnoujście;
- After the 1st stage of modernisation – 3-layer transport (60 containers) to Bytom Odrzański (including bypass of 3 bridges), unloading upper layers and bypass to Kostrzyn, loading upper layers and transport to Świnoujście.

Variant 2: Gliwice–Hamburg route

- Now – 3-layer transport (60 containers) to Brzeg Dolny (including bypass of 3 bridges), unloading upper layers and bypass to Kostrzyn, loading upper layers and transport to Hamburg;
- After the 1st stage of modernisation – 3 layer transport (60 containers) to Bytom Odrzański (including bypass of 3 bridges), unloading upper layers and bypass to Kostrzyn, loading upper layers and transport to Hamburg.

The results of the analysis are presented in Table 2. They justify the idea that it is possible to lower the transport cost of one container in this system two fold compared to railroad transport.

Conclusions

The first, tentative attempts at an economic evaluation point to the fact that there are organisational and terrain combinations which lead to establishing the percentage of use of relief roads and the number of transshipments required for the whole length of the route (Oder Waterway + sections of European roads). This indicates it may be possible to achieve a beneficial economic effect. This effect will be a cheaper transport of multi-layer containers by bypasses rather than by direct railroad transport.

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Inland waterway transport in Poland – the current state and prospects for development

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Key words: inland waterways, inland waterway fleet, infrastructure of inland waterways, cargo, capital expenditure, ecology, safety

Abstract

The dynamic development of road transport has caused an imbalance in transport systems. For the balance of the transport system, an increasingly important role should be played by networks such as railways and inland waterways, which, due to ecological aspects and minimal participation in the generation of external costs, are the most socially friendly. The layout and length of inland waterways in Poland has remained at a similar level for years. The specificity of the waterway infrastructure influences the factors that shape the demand for transportation by inland waterways. The navigation conditions impact directly the main design parameters of the ships used for transportation on inland waterways, including the relatively small carrying capacity of the barges, as well as the volume of traffic. An inadequate development of navigable waterways in Poland, concerning both natural elements (channeled rivers, free-flowing channels) and shipping parameters (discharge dimensions, depth and width of the trail, height of bridges), affects the specificity of inland navigation and relegates it to a marginal role in the Polish transport system. The share of inland waterway transport for total freight decreased from 0.8% to 0.4% between the years 2000 and 2014.

The aim of this article is to draw attention to the fact that inland shipping services, in the transport market, are sufficient to determine the existence of waterways. All other factors only stimulate or restrict its place in the transport system. The preferential use of natural waterways is the essential limitation which restricts their adaptation to the changing transport needs. Thus, the density of waterways is much lower compared to other transport networks and the development of potential inland waterway transport is primarily determined by the quality and spatial arrangement of the existing waterways.

Introduction

The common transport policy pursued by the European Union seeks to apply the principles of sustainable development to transport. This will ensure a genuine competition between the different modes of transport in favor of environmentally friendly solutions and the integration of freight transport corridors. Inland waterway transport is one of the cheapest and most environmentally friendly options.

The impact of inland navigation on the environment is relatively low compared to other modes of transport because of:

- relatively low power consumption;
- low emissions of air pollutants;

- relatively low water pollution;
- the ability to significantly reduce congestion on the roads resulting from the adoption of freight road transport;
- lower external costs.

The low energy consumption during inland navigation is a result of the smaller amount of fuel consumed in comparison with other modes of transport. In addition, the emission of air pollutants is significantly lower than the one deriving from road transport. An additional advantage of inland waterway transport is the capacity and the mass, allowing for efficient service of even the largest ships. One big barge or a pushed set can replace even hundreds of trucks. Smaller ships, operating in local waterways,

and replacing dozens of tracks, can help reduce congestion and security risks on the roads (Wojewódzka-Król, 2006).

Poland presents a modest network of inland waterways compared to both the highly developed EU countries, where inland waterways have been occupying an important position in dealing with transportation needs, which tend to integrate with the EU. Hungary, Czech Republic, Slovakia as well as Russia and Ukraine, are taking a number of actions to increase the role of inland waterways in the transport system in an attempt to catch up with the EU.

The main problems leading to the marginal importance of inland waterways in the Polish transport system have been the same for many years. Funds spent on inland water transport investment, not only did not allow for its development, but were also too small to prevent the decapitalization of existing infrastructure. This policy has led to the degradation of waterways. There has been a deepening disparity in the development of inland water, rail and road transport.

Characteristics of inland waterways in Poland

The length of the inland waterway network in Poland in 2015 remained at a similar level as in the previous year and amounted to 3655 km, of which 2417 km were regulated as navigable rivers, 644 km as canalized sections of rivers, 336 km as channels, 259 km as navigable lakes. Shipping actually took place along 3365 km of navigable waterways, amounting to 92.1% of the available network. Adjusting the size of vessels and waterways is the main factor determining the effectiveness of inland waterway transport. Requirements for roads of international importance (classes IV and V) were fulfilled in Poland in 2015 and accounted for 5.9% of the length of waterways (214 km). The share of inland waterways in this class, providing the parameters necessary for modern shipping, has not changed since 2007. The rest of the waterways have regional importance (class I, II and III), with a total length of 3441 km (94.1% of the total length of waterways) in 2015 (GUS, 2016). Table 1 shows operated inland waterways in 2015 in Poland.

The following list reports the waterways in Poland with the parameters of International Classes (state and prospects of development of inland waterway transport in Poland):

- Wisła, from the Przemsza estuary connected to the Canal Łuczyński – 37.5 km (Class IV);

Table 1. Operated inland waterways in 2015 in Poland (GUS, 2016)

Specification	Navigable-river regulated	Channeled sections of rivers	Channels	Lake navigable
in kilometers				
TOTAL	2152	620	334	259
The roads of regional significance				
Ia	641	101	168	54
Ib	608	137	–	–
II	691	106	106	168
III	115	207	47	28
The roads of international importance				
IV	–	14	–	–
Va	–	55	–	–
Vb	97	–	14	10

- Wisła, from Płock to Włocławek – 55 km (Class Va);
- Martwa Wisła – 11.5 km (Class Vb);
- Lake Dąbie to the frontier with internal sea waters – 9.5 km (Class Vb);
- Odra, from the city of Ognica to Klucz-Ustowo and continuing as Regalica up to the mouth of Lake Dąbie – 44.6 km (Class Vb);
- Western Odra – 36.3 km (Class Vb);
- Parnica and Parnicki rivers, from Western Odra to the border with internal sea waters 11.5 km (Class Vb).

The existing network of waterways in Poland is based on the natural system of rivers and the connecting channels, built mainly between the eighteenth century and the first half of the twentieth century. In comparison with other EU countries, their length is significant and represents approximately 11% (11.4%) of the total network of inland waterways of the European Union. Only Germany (6636 km), Finland (8018 km), France (5872 km) and the Netherlands (5046 km) can boast a longer network of waterways. Poland is characterized by a relatively high-density network of waterways, with 11.6 km of navigable waterways every 1000 km², compared to the EU average of 9.3 km/1000 km². A higher density ratio is present the Netherlands (121.6 km), Belgium (50.2 km), Finland (23.7 km), Germany (18.6 km), Hungary (15.5 km) and Luxembourg (14.2 km) (Adamczyk, 2011).

The technical condition of the water transport infrastructure subsystem and its role in the country's transport system is reflected in cargo volumes. Poland, despite the well-developed network of waterways, has a very low share of cargo river transport in total land freight – approx. 0.1%, while

the share of inland waterway in other EU countries stands at 34.7% for the Netherlands, 5.8% in Belgium, 12.6% in Bulgaria, 12.3% in Germany.

Gliwice Canal, was built in 1938. It is about 41 km long, has 6 twin sluices (length $L = 71.5$ m width $B = 12.0$ meters), of which three (Łabędy, Dzierżno and Rudziniec) are located within the province of Silesia. This channel provides a connection between an important industrial district with the port of Szczecin and Western Europe through the Odra River and inland canals of Germany (for example: Dortmund-Ems, Elisabethfehnkanal etc.). In recent years, the Gliwice Canal has carried about 400–600 thousand tons of cargo (mainly coal from Gliwice to Wrocław). The length of the Gliwice Canal sluices allows operating a single barge or a set consisting of one barge and towboat. Currently, pushed convoys must be strained when passing through sluices, which is a serious encumbrance to navigation. This channel does not meet the requirements of modern inland navigation. As a result of ships exceeding the 8 km/h speed limit on the channel, and the frequent passage of fleet, as well as improper maintenance, the depth of the canal has been reduced to 1.80 m (Adamczyk, 2011).

The most important factors influencing the decline of inland waterways for the transport of goods are:

- the progressive depreciation of the infrastructure and the lack of investment action that decreases the attraction of the inland waterway;
- lack of action to adapt waterways to contemporary requirements (rebuilding locks Gliwice Canal);
- low competitiveness of water transport in relation to other transportation means;
- limited availability of waterways (in the Silesian's region navigation takes place only through the Port Gliwice currently being a part of the Silesian Logistics Centre SA);
- unfavorable conditions for navigation on the middle section of the Odra, which impedes navigation between the upper and lower sections of the Odra.

The layout and length of inland waterways in Poland has remained at a similar level for years. In 2014 there was an increase of cargo volumes transported by inland waterway ship owners. This increase was related mainly to domestic transport (GUS, 2015). Table 2 presents of goods by inland waterways in Poland in 2014. The information has been classified in terms of origin/destination.

In 2015, 11,928 thousand tons of cargo were transported along inland waterways, for a total of 2,186.8 million tkm. In comparison with the previous year,

Table 2. Inland waterways transport of goods by origin/destination in 2014 in Poland GUS, 2015)

Voivodship or country		Tonnes	Tonne-kilometres
From	To	In thousand	
National transport			
Dolnośląskie	Dolnośląskie	3715.3	29548.7
Kujawsko-pomorskie	Kujawsko-pomorskie	501.4	1622.9
Małopolskie	Małopolskie	53.1	826.1
Opolskie	Opolskie	7.3	36.5
Opolskie	Śląskie	23.7	1068.8
Świętokrzyskie	Świętokrzyskie	24.8	626.9
Zachodnio-pomorskie	Zachodnio-pomorskie	500.5	33597.6

there was and a 56.4% increase of freight, expressed in the number of transported tons, while the size of the transport increased by 180.9%. The largest increase was in shipped tons of cargo (146.0%), while increasing the size of transport work (298.6%) occurred in the first quarter (GUS, 2016). Figure 1 shows transport of goods by inland waterways by quarter in Poland.

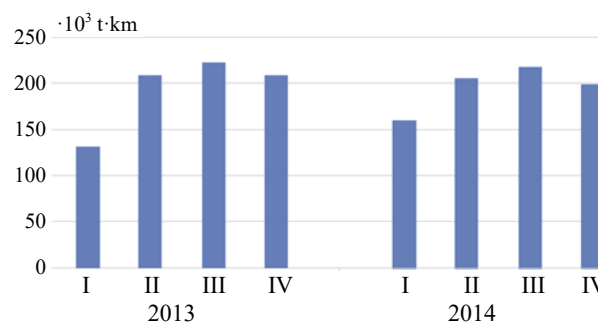


Figure 1. Transport of goods by inland waterways per quarter (GUS, 2016)

In 2014, the average distance for the transport of 1 ton of cargo amounted to 253.4 km (in 2013, 252.6 km) for international traffic, and 14.5 km (in 2013, 25.6 km) for domestic transport. The high average distance travelled in international transport is due to the dominant share of freight transport on the Western European waterways. Compared to 2013, there was a 116.8% increase of domestic carriage to 4833 thousand tons (mainly cargo from group aggregates, sand and stone), with an increase in traffic of 22.9%, up to 70.0 million tkm. Such a significant increase in traffic was associated primarily with the participation of inland waterway transport in the “Modernization of Wrocław Floodway System” project.

In 2014, international traffic amounted to 2,796 thousand tons of cargo (0.7% less than in the previous

year), which accounted for up to 36.6% of all cargo transported by Polish ship owners. The volume of traffic between foreign ports decreased by 3.9%, and their share of international transport in the total transport decreased from 70.2% in 2013 to 67.9% in 2014. Imported cargo was also reduced (40.7%), while there has been an increase in freight exports (16.6%). The main direction of export by inland waterways (representing 29.2% of total international transport) was towards Germany. The share of transport in this direction amounted to 92.0% of total exports using waterways (GUS, 2015). Figure 2 presents the structure of freight transport by inland

waterways, according to the 2014 directions, and its changes in relation to 2013.

In Poland, the structure of freight in 2014, as in previous years, was dominated by transport of metal ores and other mining and quarrying products (65.6%) and a group of hard coal and lignite, oil and natural gas (14.9%). Figure 3 presents structure of freight transport by inland waterways according to the main commodity groups in 2014 and its changes in relation to the previous year.

Prospects for the development of inland waterway transport in Poland

The key document determining the rationale for using Polish waterways is the European Agreement on the main waterways of international importance (Agreement AGN), signed in 1996. According to this document, the Polish territory possesses three international waterways, connecting the port of Silesia, Warsaw and waterways of Belarus, Germany and Russia. The document shows the advantages and prospects for the Polish inland waterways, particularly international navigation. Poland is the only country in Central Europe, which has not participated in the Agreement – its signatories include all the neighbors of Poland, including non-EU countries.

The “Diagnosis of Polish transport”, prepared by the Ministry of Infrastructure states that “the Polish network of waterways does not create a uniform system of communication, but a collection of

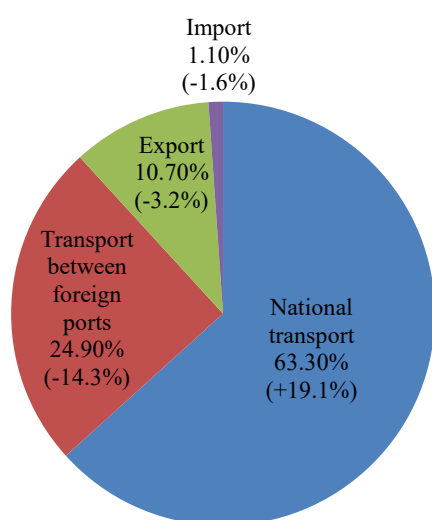


Figure 2. Structure of freight transport by inland waterways according to the 2014 directions and its changes in relation to the previous year (GUS, 2016)

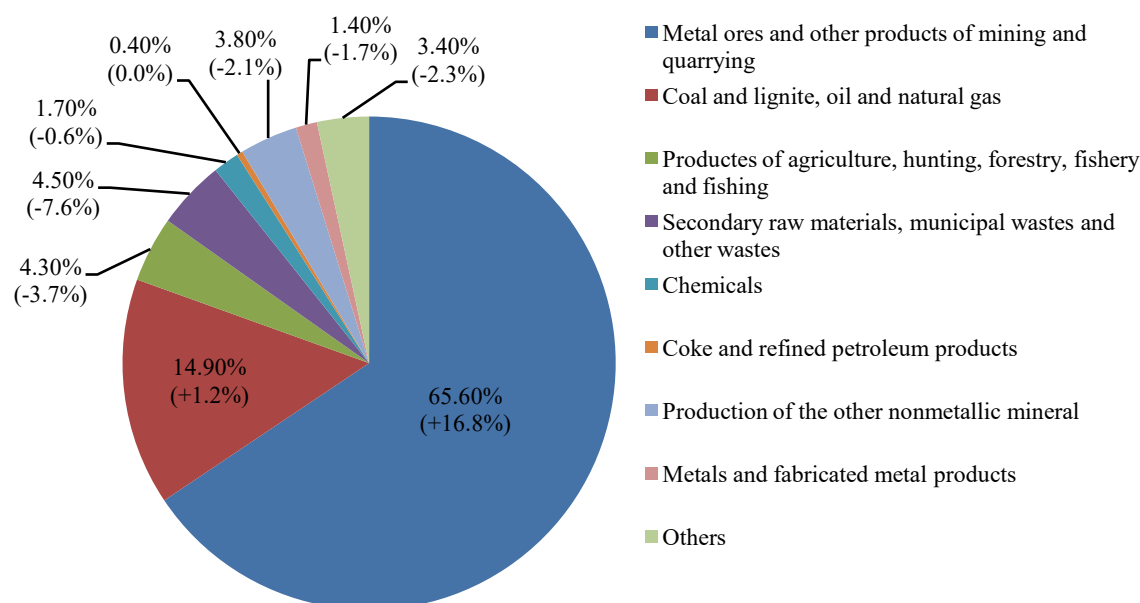


Figure 3. Structure of freight transport by inland waterways according to the main commodity groups in 2014 and its changes in relation to the previous year (GUS, 2016)

separate and qualitatively different shipping lanes” (Diagnosis Polish transport, 2011). As a result, the transportation on short distances dominates, often limited within the same province (Galor & Dwojacki, 2011).

Meanwhile, the “White Book 2011” proposes that distances over 300 km should be covered by alternative means of transport (railway, water transport). This switch should be obtained progressively, reaching 30% by 2030 and 50% by 2050. The White Paper (White Paper, 2011) postulated a tight integration of inland waterway transport with seaports. This means, in practice, joining at least navigable sections of rivers. Indeed, this would be a significant factor in increasing the possibility of cargo transport over long distances.

Poland has one of the most developed networks of rivers in Europe, which has a long history of intensive use for transportation purposes. The system of rivers is closely correlated with the structure of the settlement and distribution of economic potential, including all the key metropolitan areas and industrial centers. Estuaries and seaports are also present within the state border. The system of waterways is in line with the course of the main cargo flows. We hope that the implementation in Poland of techniques and technologies associated with the development of the rivers will, in the future, be directed towards a reduction in costs (including those of an environmental nature) (Dwojacki, 2011).

The increasing level of importance of transport for the competitiveness of a supplier will affect the development of inland navigation. The result is likely to be associated with lobbying and business initiatives for water transport.

Conclusions

Polish inland waterways play a marginal role in the Polish transport system. The share of inland waterway transport in total freight transport in the period 2000–2014 decreased from 0.8% to 0.4%. This results from an insufficient development of navigational roads, as well as navigational parameters

(the dimensions of sluices, the depth and width of the trail, the height of bridges).

Polish strategies and national policies differ significantly from European documents. Poland primarily intends to participate in the AGN Agreement on the inland waterways of international importance. Polish waterways are attached to shipping routes considered vital for the integration of the European network of waterways, or category E. The AGN Agreement will apply to roads that already have the appropriate classification requirements and pathways that are intended to reach international standards in the future (Maritime, 2016). For Polish inland waterways of category E to meet the requirements of shipping routes of international importance, they must be developed or upgraded to class IV navigability.

In Poland, rivers and channels are important from the point of view of transport and will be awarded the international class IV navigable level. The Odra (along its entire length) and Wisła (from Warsaw to Gdańsk) will become international shipping routes by 2030.

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Attempts to protect the internal market for road transport in specific European Union countries

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Key words: liberalisation, protectionism, minimum wage, European Union regulations, restrictions, limitations

Abstract

The seven-year period to adapt internal law to EU regulations was given to new Member States on 1 May 2004 and ended in 2011. The highly-developed western states, fearing that their internal markets in fields such as transport services may be threatened, adopted a number of new regulations. Regulation (EC) No. 1072/2009 of the European Parliament is on common rules for access to the international road-haulage market, and despite introducing numerous restrictions, was to regulate cabotage operations in all Member States. However, the protection of each State's own interests proved more important than the integrity of the Community and therefore some of the states, including Germany, have introduced severe limitations for foreign carriers, forcing them to observe the Minimum Wage Act (MiLoG).

Introduction

The creation of a common transport policy within the European Union involves abolishing all limitations for service providers that arise from their nationality or if they have their seat in a different member state than where the service is provided. Such action was forced by the introduction of the Four Freedoms, adopted by the community in the Treaty of Rome and implemented by the Schengen Agreement. The establishment of the common transport policy involved, inter alia, the determination of common principles governing the access to the international transport market in the territory of the Community that would contribute to efficient functioning of their internal transport market. The gradual implementation of the European Single Market should be aimed at abolishing all limitations in the access to internal markets of Member States, including cabotage (cabotage is a type of carriage of goods performed with a vehicle registered abroad or by a foreign company between places located in the territory of the native country).

Liberalisation

In order to ensure a coherent framework for international road haulage throughout the EU, the Community has adopted Regulation (EC) No. 1072/2009 on common rules for access to the international road-haulage market in the EU territory (Regulation, 2009). Prior to the implementation of Regulation (EC) No. 1072/2009, carriage was regulated by the following EU acts of legislation: Council Regulation (EEC) No. 881/92 and (EEC) No. 3118/93, and Directive 2006/94/EC. Those regulations did not, however, give hauliers as many rights as they have now, mostly because of the time limitations in cabotage operations. Now hauliers may perform such operations all the time.

Carriage from Member States to third countries is still largely covered by bilateral agreements between the Member States and those third countries. Therefore, that Regulation should not apply to that part of the journey within the territory of the Member State of loading or unloading, as long as the necessary agreements between the Community and the

third countries concerned have not been concluded. It should, however, apply to the territory of a Member State that is crossed in transit. Transit is the movement, by means of transport, of persons, cargo, energy, and/or information from one country to another via the territory of a third country that is neither the country of origin nor the country of destination.

Regulation (EC) No. 1072/2009 applies to the international carriage of goods by road, for hire or reward, for journeys carried out within the territory of the Community. The Regulation also applies to the national carriage of goods by road undertaken on a temporary basis by a non-resident haulier. The Regulation also defines who is entitled to carry out cabotage operations: it is any haulier for hire or reward who is a holder of a Community licence and whose driver, if the driver is a national of a third country, holds a driver attestation.

The Community licence is issued by a Member State, in accordance with the Regulation, to any haulier carrying goods by road for hire or reward who:

- is established in that Member State in accordance with Community legislation and the national legislation of that Member State;
- is entitled in the Member State of establishment, in accordance with Community legislation and the national legislation of that Member State concerning admission to the occupation of road haulage operator, to carry out the international carriage of goods by road.

The Community licence will be issued by the competent authorities of the Member State of establishment for renewable periods of up to 10 years. The Member State of establishment will issue the holder with the original version of the Community licence, which must be kept by the haulier, and the number of certified-true copies corresponding to the number of vehicles at the disposal of the holder of the Community licence, whether those vehicles are wholly owned or, for example, held under a hire purchase, hire or leasing contract. These requirements, according to EU regulations, concern the issuing of the Community licence entitling to carry goods by road for hire or reward in the territory of the EU Member States.

The effectiveness of implementation of the European Single Market should be aimed at abolishing all limitations in access to the internal markets of the Member States. The European Council plays a significant role in this, as one of its tasks is the scrutiny of the market situation and the course of harmonization of Community rules in the fields of, *inter alia*,

enforcement and road user charges, and social and safety legislation. The implemented rules will lead to the further opening of domestic road-transport markets, including cabotage.

New rules concerning cabotage have been applicable since 14 May 2010. The European Parliament enforced the liberalisation of the existing rules by implementing the Regulation of the European Parliament and the Council regarding common rules for access to the international road-haulage market. It defines cabotage operations as “national carriage for hire or reward carried out on a temporary basis in a host Member State”.

In accordance with said rules, once the goods carried in the course of an incoming international carriage have been delivered, hauliers are permitted to carry out, with the same vehicle, up to three cabotage operations following the international carriage from another Member State or from a third country to the host Member State. The last unloading in the course of a cabotage operation before leaving the host Member State must take place within 7 days from the last unloading in the host Member State, in the course of the incoming international carriage (Kochanowski, 2010). Hauliers may carry out some or all of the permitted cabotage operations in any Member State under the condition that they are limited to one cabotage operation per Member State within 3 days of the unladen entry into the territory of that Member State.

National road haulage services carried out in the host Member State by a non-resident haulier are only deemed to conform to the Regulation if the haulier can produce clear evidence of the incoming international carriage and of each consecutive cabotage operation carried out.

What does the three day period mean? The haulier may, within seven days, carry out a cabotage operation in one or more Member States. The maximum number of operations is three. The haulier may decide to perform one, two, or all three operations not only in the host Member State in the course of the incoming international carriage, but also in other Member States. In that case, the haulier may perform only one cabotage operation in a given Member State and this operation must be performed within three days of the unladen entry into the territory of that Member State.

The period of seven days, referred to in the Regulation, concerns calendar days and begins at 0:00 of the day following the last unloading that took place during the incoming international carriage. The last unloading during the final cabotage operation should

end at the latest on the seventh day at midnight (Regulation, 2009).

The term “cabotage operation” (the term is interpreted based on common practices in road transport) refers to carrying goods from the moment of taking the goods to the moment they are delivered to the consignee, according to the consignment letter. Such an operation may include a few (or even several) loading points and as many delivery points, depending on the circumstances. The first cabotage operation may happen only when the transboundary carriage has ended and it is only then that the seven-day period for cabotage operations starts.

Freeing up the transport market of Member States has also introduced new perspectives for Polish hauliers. Poland has also been obliged, as a Member State, to regulate the matter of cabotage operations in its territory. Polish hauliers have specialised in keeping very high standards while providing international transport services. It is a relatively young business, using state-of-the-art means of transport. According to Polskie Forum (Polskie Forum HR, 2016), Polish companies currently have around 100,000 lease agreements for tractors and trailers, with a total value of around 10,000,000,000 PLN. The employment in the transport sector may be as high as one million people. The significant scale of activity means that Polish transport companies operate using a relatively-low profit margin and therefore are really competitive in the international transport market.

Protectionism

Each Member State, in order to protect its own internal and international market, tries to enforce the policy of protectionism so that the interests of their internal hauliers are protected. It mostly concerns states whose own costs are high (i.e. wealthy EU countries). The enforcement authorities in these countries watch other hauliers performing cabotage operations very closely and introduce their own internal regulations, the breach of which results in heavy penalties.

The state that makes it particularly difficult to perform cabotage operations in its territory is Germany; they introduced obligatory cabotage insurance. By virtue of paragraph 7a, items 1 and 2 of the German Road Haulage Act (Güterkraftverkehrsgesetz), transport companies performing carriage in the territory of Germany are obliged to have a valid, carrier, third-party liability insurance (Waldendorfer, 2010). The minimum amount of cover for all

events amounts to 1,200,000 EUR with the limit of 600,000 EUR for an individual event. The cabotage insurance is obligatory only for those hauliers who perform the carriage of goods by road as part of their business activity, using the vehicle with the maximum permissible laden mass, including the trailer, when it exceeds 3.5 tonnes. Despite this, it is often bought by companies that have smaller vehicles.

In order to meet the requirements of the appropriate insurance, the sufficiently-high amount of cover is a necessary condition but it is not a sufficient condition. The insurance must also meet one other criterion, concerning the exclusion of liability. Therefore, only the following may be excluded from liability:

- intentional guilt of transport operators or their representatives. It is therefore gross negligence of both operators themselves and their representatives that is subject to insurance. Also, the intentional guilt of persons for whom the operator is responsible but who are not their representatives is subject to insurance. It is usually the driver employed by an employment contract or by mandate contract;
- damages caused by natural disasters, nuclear energy, war, war-like events, civil war, civil unrest, strikes, terrorist acts of violence, orders of higher authority, or taking or seizure ordered by a state-recognised authority;
- in view of the nature of the goods, the following claims from the contract of carriage may be excluded from the insurance: the transport of precious metals and stones, jewels, means of payment, assets, securities, stamps, documents, and certificates.

Furthermore, in order to meet the requirements of the insurance obligation, the insurer must authenticate the presence of the insurance policy that meets said requirements by having an appropriate certificate in German and notify the Federal Office for Goods Transport (Bundesamt für Güterverkehr) that such insurance has been concluded and/or terminated. The driver must have this certificate while performing cabotage operations in the territory of Germany and present it immediately upon the request of authorised bodies. The lack of said certificate alone may result in a fine in the amount of 5,000 EUR.

German Act on the Regulation of a Minimum Wage (MiLoG)

The seven-year period, which is just coming to an end, for adapting internal law of new EU members to the EU law, has aroused anxiety about migration.

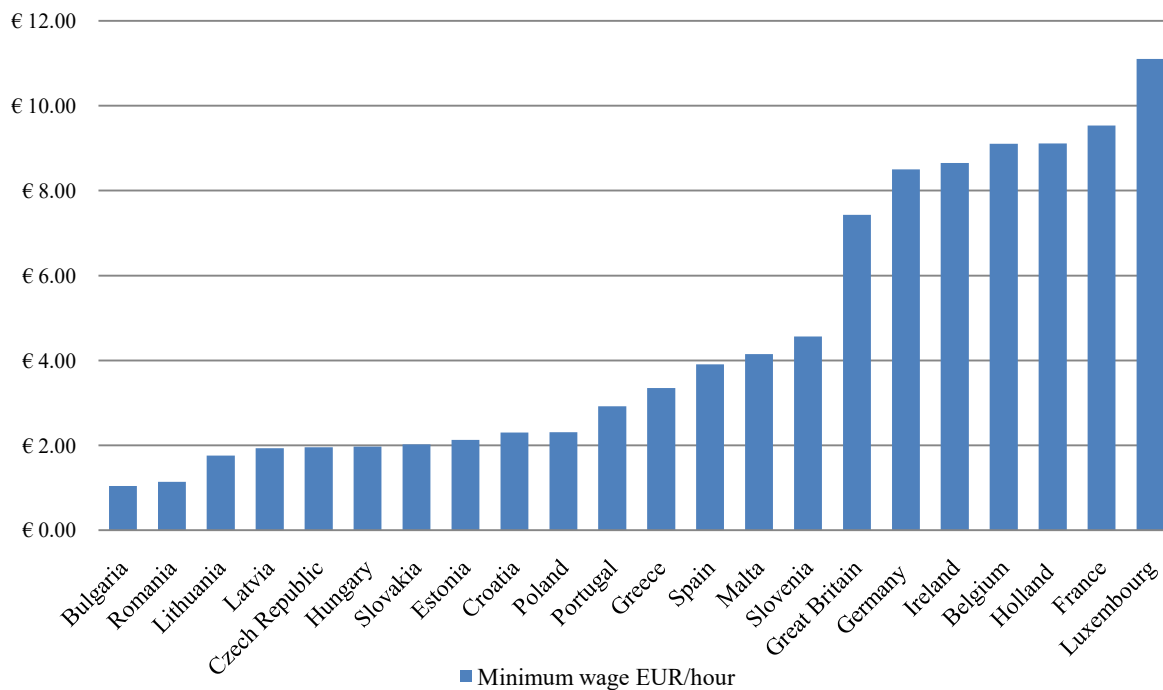


Figure 1. Minimum wages in EU Member States (WSI-Mindestlohndatenbank, 2014)

The discussion on the minimum wage resulted mostly from the fear of opening the borders for foreign workers on 1 May 2011. As early as 2010, German politicians and trade union leaders motioned to establish a minimum wage at 7.50 EUR per hour. This amount was to ensure the support of the family and prevent the state from the necessity to pay additional benefits for old-age pensioners. 1 May 2011 marked the end of the 7-year period (so-called transitional period) that countries that entered the EU structures on 1 May 2004 had been given to adapt their internal law to the EU law. This date was also the day on which the internal markets of EU countries were opened to new members.

Trade-union leaders were afraid that home companies would want to employ workers from Poland or the Czech Republic, ready to work for 4.00 EUR per hour, and not Germans who were guaranteed by collective agreements a rate of pay higher by 2.00 EUR. Figure 1 shows the minimum wages for various EU Member States.

The currently-applicable Minimum Wage Act is of much higher significance. It settles the minimum wage rate at 8.50 EUR for each hour of work and rest in the territory of Germany during the performance of international transport (via German territory) (Polskie Forum HR, 2016).

The German minimum wage also applies to foreign employers with their seat outside the borders of Germany. It results from the specific definition of

a driver's workplace. In this case, the interpretation and argumentation of German authorities is as follows: "a driver's workplace is simply the vehicle. Therefore, the employer must pay the German minimum wage as the vehicle is used on German roads". This law also applies to railway transport, sea shipping, and inland navigation.

In this case, the provisions of German administration do not take into consideration the peculiar structure of income of drivers from other countries (Federal Office for Goods Transport, 2009). For instance, Polish drivers receive from their employers, apart from regular remuneration, additional assets for business expenses or an allowance for accommodation (about 49.00 EUR per day). A German employer in the same situation is obliged only to pay the minimum wage and does not need to worry about neither business expenses nor accommodation costs.

The German administration, apart from the MiLoG act, also cites the provisions of Directive 96/71/EC, which obliges international entities that post workers to provide services in the territory of Germany to observe the conditions of minimum wage and others.

An explanation should also be provided for the interpretation of item 17 of the preamble to Regulation (EC) No. 1072/2009, which regulates the common rules for access to the international road haulage market, which allows in certain situations to qualify cabotage as posting workers. What, therefore, is the

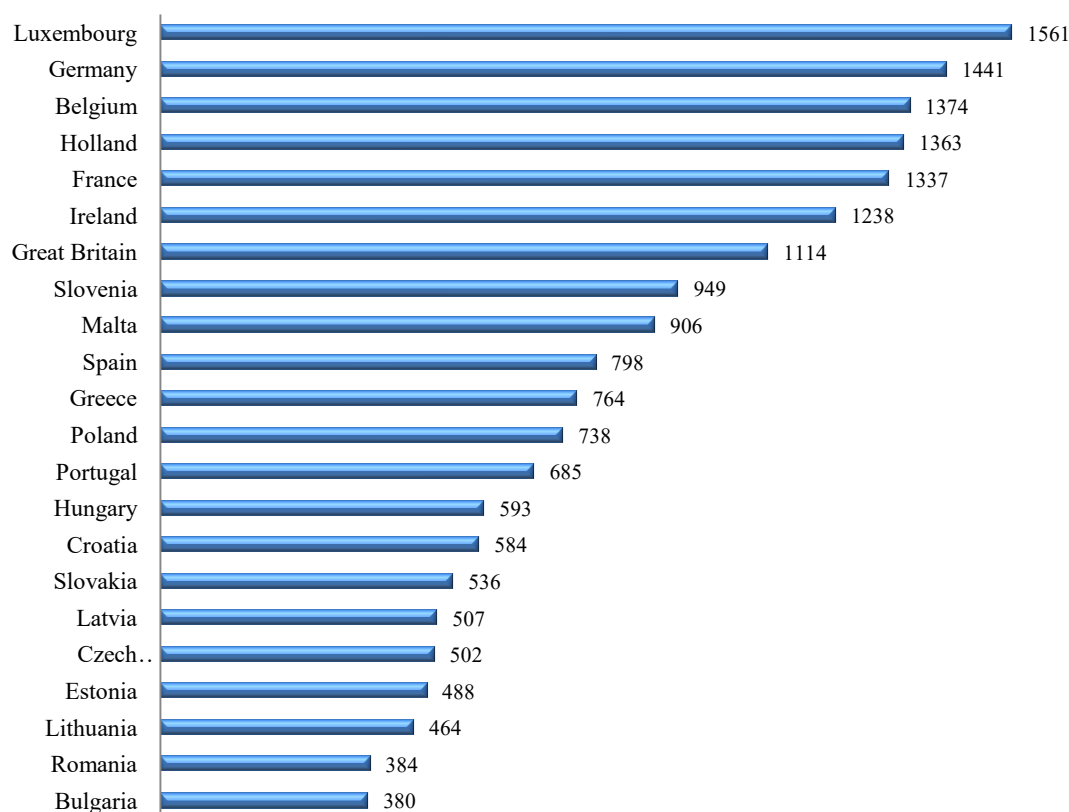


Figure 2. Minimum wage in EU Member States as of January 2015 (PPS)

argumentation of the Polish law? Performing transport operations by a driver falls into the definition of travel by staff members on duty (Article 775 of Polish Labour Code). The Supreme Court, in its judgement No. II UK 204/13, confirmed that travel by staff members on duty is brief and incidental and does not cause the change of an established workplace. What is important to drivers in international transport is that even if they are abroad for several weeks, they do not perform one trip but rather tasks constituting multiple business trips. Another significant fact is that Polish drivers working in the territory of Germany, performing carriages with Polish vehicles, based on the licence issued in Poland, are not workers posted to provide services in the territory of Germany, and therefore under no circumstances are bound by the amendment to the MiLoG act concerning minimum wage (WSI-Mindestlohn-datenbank, 2014).

When interpreting EU regulations concerning the definition of workers posted in the framework of the provision of services, one can conclude that it is a worker sent to another Member State in order to provide, in a defined time and place, a specific service for the commissioner from the host country. In the case of transport, it would be the carriage of goods with the use of means of transport belonging

to the haulier, under the direction and supervision of this haulier solely. The rules governing the method of performing the transport operation are established with the Polish company, with its registered seat in Poland. Even when the carriage is performed in the territory of Germany, it still is not the posting of workers, since that must have been connected with changing a given workplace and submitting to German direction and supervision. As long as the driver provides carriage services based on a licence issued by Polish administration, with the use of a vehicle registered in Poland, this driver is on a business trip and is not a posted worker. However, if a Polish carrier puts its drivers at the disposal of a German entity and the driver will provide services based on a license issued by German authorities, then it will be a posted worker and this worker will work according to the conditions set forth in the MiLoG act but will not be reimbursed for business expenses or accommodation costs.

According to foreign carriers, adopting the Minimum Wage Act imposes additional difficulties on them. The new regulations oblige foreign transport companies to notify German customs authorities about the date of entering and leaving the territory of Germany. Such notification must be sent via fax message (it is impossible to make the notification

via electronic mail) and all data must be presented in German. Such action causes additional bureaucratic problems and real costs.

Conclusions

German regulations concerning the minimum wage, according to Polish entrepreneurs, infringes the freedom to provide services, as defined in Article 56 of the Treaty on the European Union. The amended German MiLoG act may also be in breach of several EU regulations concerning access to carriage services. The European Council has analysed the legality and proportionality of the enforced duties and considers whether or not it is aimed at restricting access to the German market. In case such a conclusion is reached, the Council promises to initiate proceedings in the matter of an infringement of the EU law. The European Council is preparing to initiate proceedings against Germany for infringing the EU law concerning transit. In the preparation of a motion concerning cabotage, the decision to file the motion has been postponed, should the matter be resolved amicably.

The provisions on the minimum wage passed by German authorities have struck Polish transport companies in particular. The geographical location results in us being somewhat cut off from Western Europe. The new minimum wage may increase costs up to 9%, which will significantly affect the

competitiveness of Polish carriers. The change in legislation also concerns employed drivers, and their opinion is ambiguous as they want their remuneration to rise. The matter concerns the whole business, hence the unequivocal action of Polish government in order to maintain Polish carriers' share in the European market and to preserve workplaces.

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The concept of multipurpose inland residential platforms used on European waterways

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Key words: residential platforms, inland waterways, floating barges, houseboats, water tourism, legal regulations

Abstract

This article analyzes the concept of multipurpose inland residential platforms. It presents the existing solutions and the applications of floating residential structures in Europe, including houseboats and floating barges. Further on, the paper describes the possibilities and main purposes of using multipurpose inland platforms (residential, tourist or military). In addition, an algorithm is presented for selecting the right concept depending on the demand and the infrastructural conditions of inland harbors and marinas. Three variants of residential platforms are identified and the features of some of the solutions are discussed. The expected benefits for different sectors of the economy derived from using residential platforms are also explored. The aforementioned analysis prescribes the directions for further research aiming to ensure effective implementation of the presented concepts.

Introduction

The ever larger and faster development of urban agglomerations in Poland and other European countries, leading to a gradual increase in the prices of building land combined with its limited resources, forces investors to look for new architectural and spatial residential solutions that will have a wide range of applications. It also appears that in view of the construction industry of the future, the existing ideas for dwellings still leave a lot to be desired and the current proposals are considerably insufficient. The use of floating barges for residential purposes is one solution to these problems that is already being explored in Western European countries. However, the scale of this application has not yet grown enough for it to be deemed a common phenomenon.

The applications implemented so far are limited to adapting existing transport units to take residential roles. In terms of the present building standards and safety requirements for transport units, this solution must naturally undergo modification and adaptation. Modifications, undoubtedly, should first of all be made to legal regulations related to, for instance, the possibility of securing residential registration, while the first steps in terms of “homes on boats” have already been taken, with the first inhabitants of Warsaw and Wrocław starting to use this form of residence. In the future, adapting the technical conditions of such housing estates’ operation and management will constitute a separate legal problem. While the residential use of waterways is becoming more and more popular, the legal regulations concerned will need to be systematized.

One crucial purpose of this article is to present alternative construction forms of residential platforms. In the future, the solutions discussed herein may be of enormous significance to new spatial development ideas, as well as the development of new sectors of industry and services. This is because the subject concerned combines knowledge from such fields as architecture, civil engineering, hydraulic engineering and shipbuilding. Requirements concerning the natural environment, material science and modern technology applications in industry should be imposed on these domains of science. The authors have attempted to combine all these domains in order to provide a realistic perspective for the development of the shipbuilding industry, which is undergoing a period of stagnation in Poland, and civil engineering, which is currently experiencing a downturn due to the crisis in global financial markets.

The scientific purpose of this paper is to develop an initial concept of multipurpose residential platforms designed for inland waters, together with proposals for their destination as permanent or temporary dwellings. This is because although the very concept of “living on a boat” is not new, it is still treated as a certain type of extravagance or, alternatively, a cheaper way to live for the less well-off. It should be noted that, at present, this type of housing is competitive both in financial and operational terms when compared to traditional residential building.

Existing solutions and the use of floating residential structures

At present, wharf urbanization is assuming growing importance. In some European capital cities, such as Amsterdam, London and Paris, residential



Figure 1. An example of a residential barge on an inland canal in Amsterdam

barges and boats (so-called houseboats) are commonly used as permanent flats, being moored to the banks of rivers or canals, or more typical houses on water are used. In Amsterdam, which boasts an expansive inland canal network, entire housing districts form, standing out with their high esthetic values resulting from the numerous colors used and the greenery grown onboard (Figure 1).

In London, too, whole estates of residential barges and boats are created on its canals and on the Thames. They provide accommodation to approximately ten thousand people; the lower costs involved in running this type of dwelling are a popular factor when it comes to choosing to have one. Living on water is economically competitive when compared to flats and houses on land, and many people favor the first type out of necessity rather than extravagance or deliberate need of such a lifestyle. Hence, apart from exclusive structures in attractive locations with rental fees exceeding 600 pounds a month, we can also encounter “floating slums” composed of structures erected on barges unfit for navigation inhabited by low-income persons (Sibilak, 2014).

In Poland, as well, some cities have seen the emergence of houses on water or residential barges, although they are not yet popular, and are rather examples of a niche trend, which results from a number of problems related first of all to the legal regulations pertaining to the building or adaptation of such objects for residential purposes (Kaźmierczak & Zaremba, 2013).

The first floating home in Poland was built in 2012 in Wrocław and a few similar structures have already followed. Other cities that can boast their own floating houses are Warszawa, with barges adapted to residential purposes moored in Czeraniaków harbor, and Gdynia with its floating hostel (Kozicka, 2012; Kozłowska, 2012). Soon, a floating house is to be built in Szczecin, where the investors are involved in applying for the required permits and in building such a vessel. Moreover, it should be noted that the market is seeing the emergence of companies offering residential boats or similar solutions for tourists. For example, it is now possible to rent floating all-season cottages located on Lake Jamno in Mielno, or to charter low-speed motor barges in the Masurian Lake District (DNV Tours, 2016).

Possibilities and purposes of using inland residential platforms

Until recently, the adaptation of transport units has mainly been limited to their modification for

residential purposes. Well-developed wharf infrastructure in some cities allows for this type of residential construction to emerge. For some, this serves as a cheaper form of accommodation, while for others it is a way to escape the routine and mundanity of everyday life. Often, illegal boats belonging to immigrants or the unemployed are stationed alongside authorized craft, as the costs of such living are considerably lower.

Tourism, pursued both individually by families and collectively by organized groups, can be another equally valid reason for using this type of accommodation. This will certainly require the entire technical infrastructure to be tailored to the needs of business activity, but will also contribute to this industry's development by providing an alternative way of spending one's leisure time on water. The mobility factor of various residential systems allows holiday-makers to spend their time off-work actively and may be an excellent complement to the already existing tourism and recreation options. Inland residential barges can be used as typical stationary, overnight accommodation establishments at harbor wharfs and marines for collective tourism clients, or as mobile craft, chartered by families or organized groups for specific periods of time. Yet another application of

these transport units is their adaptation to serve the needs of anglers. Angling is a noticeably popular pastime and more opportunities for an interesting and organized leisure of this kind should be created.

The utility of mobile residential platforms can also be an interesting alternative for such uniformed services as the army or the border guard. By virtue of the function held by these institutions, constant deployment of troops is now more of a necessity. While the construction of traditional flats, barracks or dormitories is very costly and time-consuming, the opportunity to manage mobile accommodation systems complying with the modern residential standards appears to be an interesting proposal. Table 1 groups the main options for using multipurpose inland residential platforms.

For users and inhabitants of various types of transport unit, access to appropriate infrastructure and resources is of crucial importance. Having permanent access to water, electricity and sewerage is the basis for such structures' operation. Moreover, it is also important for living on them to be possible all year round, rather than in selected seasons. The current navigation season on inland waterways must not be obligatory for these vessels, as that would make their proper operation impossible.

Table 1. Application of inland residential platforms

No.	Application	Comment
1.	Alternative for permanent residential construction	Gathering several or a few dozen inhabited transport units at one location would allow for the creation of residential estates which, apart from their main (residential) function, would additionally contribute to the spatial development of the waterside, increase the area's esthetic value, and thus facilitate the development of tourism and inland navigation. In Poland, this solution has not become popular yet, and is only to be found in a few places.
2.	Temporary substitute accommodation	So far, such transport units have not been used as social facilities, but can be proposed as an alternative for local governments of waterside cities and municipalities, which could use them in emergencies such as fires, gas explosions, etc., where flats are lost. This would release the authorities of the need to keep and maintain such transport units within a single municipality; rather, a larger region would be responsible for them. Thus, the maintenance costs would be distributed over a number of entities and would not be an extensive burden for any of them.
3.	Temporary stationary and/or mobile military bases	In this case, there is a possibility of using mobile transport units both as typical military units and residential estates for soldiers with their families in connection with the frequent changes of their deployment.
4.	Stationary collective tourism overnight accommodation establishments	Some regions that are attractive to tourists lack the possibility of developing traditional tourist infrastructure due to unfavorable land and hydrological conditions, or any pre-existing infrastructure. In such cases, the creation of waterborne accommodation facilities is available as an alternative solution.
5.	Mobile tourist transport unit	Spending one's leisure-time on water has always been a huge attraction and is becoming more and more popular, although not everybody can afford to buy and maintain a yacht or a boat. The possibility of chartering such transport units will increase the availability of this form of tourism.
6.	Establishment for anglers	The large popularity of angling in Poland favors the offering of a few days' angling trips. The offers made by companies so far have been mostly for sea angling or fishpond angling. The possibility of organizing angling trips on inland waterways, using a transport unit with expanded angling amenities and overnight accommodation establishments, is definitely an interesting alternative. This solution could be applied on regulated rivers, as well as on larger lakes or canals.

An analysis of the concept of multipurpose inland residential barges

The various existing and currently used solutions for residential structures are a basis for the creation of a new concept of multipurpose inland residential barges. As they will be operated in the aquatic environment, there are a number of technical and operational requirements that need to be addressed in order to ensure safety and a relevant residential standard. The possibilities and destinations for inland residential platforms presented in the chapter *Possibilities and purposes...* of this article, present a number of concepts for such vessels. They could be single-purpose transport units (e.g. residential, tourist or military), or multipurpose floating structures, easily adaptable to changing needs. Here, a fixed single-hulled structure or a double-hulled vessel (catamaran) can be proposed. The latter solution would probably be of significance if it were used for tourist purposes, due to its visual attractiveness and good resistance and propulsion properties. When it comes to military use, esthetic values do not matter very much, where it is rather simple solutions, evading unwanted attention and high technical and operational parameters, allowing for the unobstructed running and relocating of the vessel, that play a crucial role. Figure 2 shows a basic classification of inland residential platforms.

The first step to take in developing concepts of multipurpose inland residential platforms is to define the basic assumptions that will include: the cruising or stationing area, deadweight tonnage and operating speed. The next step is to estimate the main dimensions (overall length, length between perpendiculars, breadth, height, draft, block coefficient, brake

power). Subsequently, the main technical standards regarding the following should be worked out:

- a) load-bearing systems of the platform's structure, bearing in mind:
 - buoyancy;
 - the effect of the hydrological and meteorological conditions;
 - fire safety;
 - vessel traffic safety;
 - structural durability and strength;
 - stability and unsinkability;
- b) the structure of the modules or the residential superstructure, bearing in mind:
 - the technical conditions that the buildings and structures would need to meet, and their location;
 - using renewable sources of electricity and thermal energy;
 - wastewater disposal and/or treatment;
 - abstraction and use of water for household purposes (precipitation or water abstracted directly from the land).

In terms of their structure, inland residential platforms may have different applications, as shown in the diagram on Figure 3. A residential platform with a fixed superstructure is proposed for the purposes of building fixed or temporary residential estates, and as stationary or mobile tourist establishments. Single or double-hulled residential platforms with replacement functional modules could be used as a temporary military base or as an angling mothership. For both these cases, universal replacement modules or specific-purpose modules can be suggested, e.g. serving as angling equipment storage, munitions storage, a utility compartment, etc., with fixed or replaceable furnishing (Kaup & Semenov,

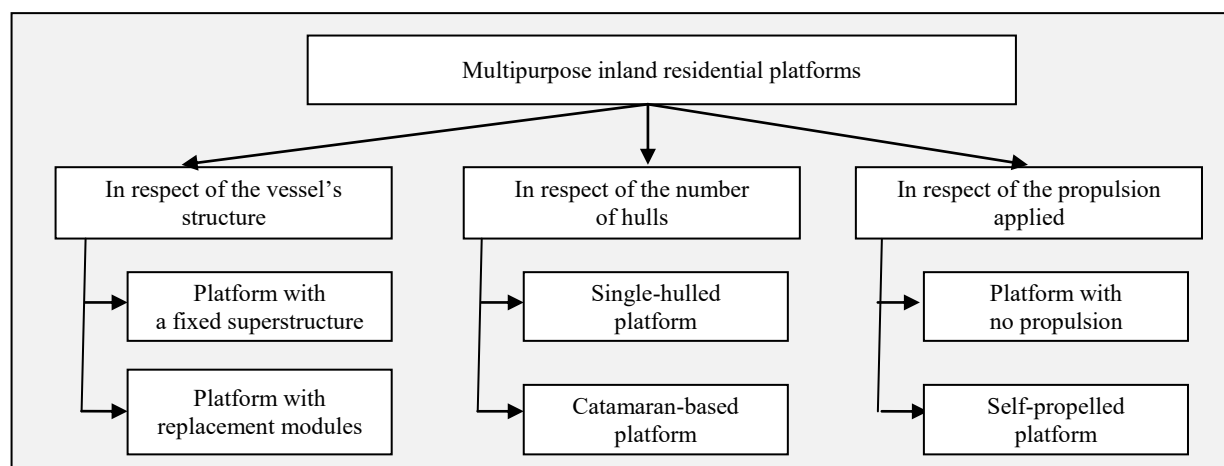


Figure 2. Classification of multipurpose inland residential platforms

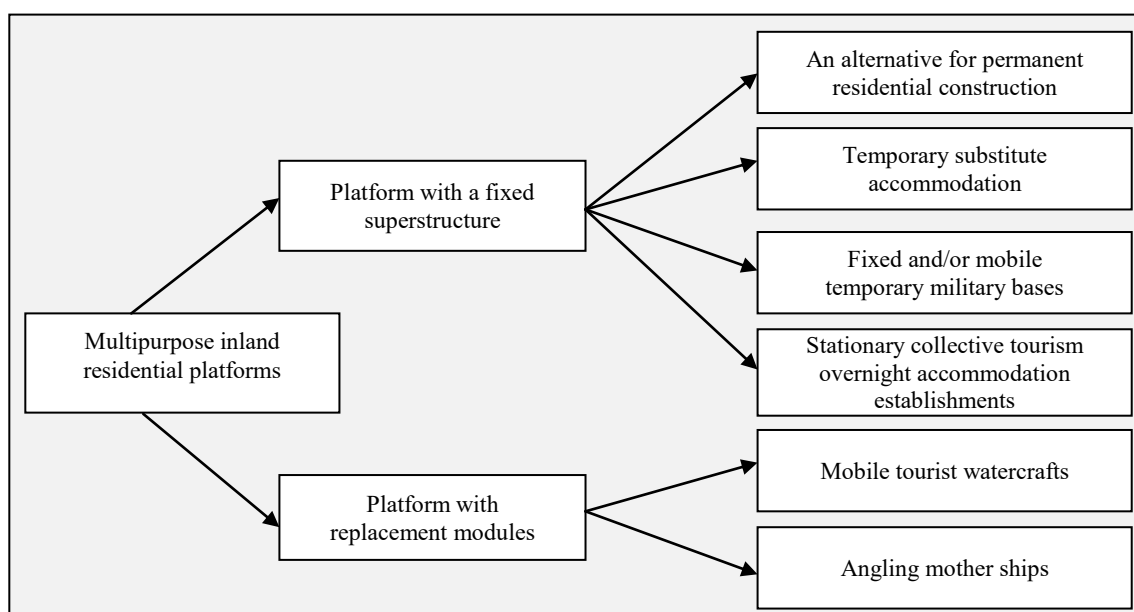


Figure 3. Variants of multipurpose inland residential platforms and their main application

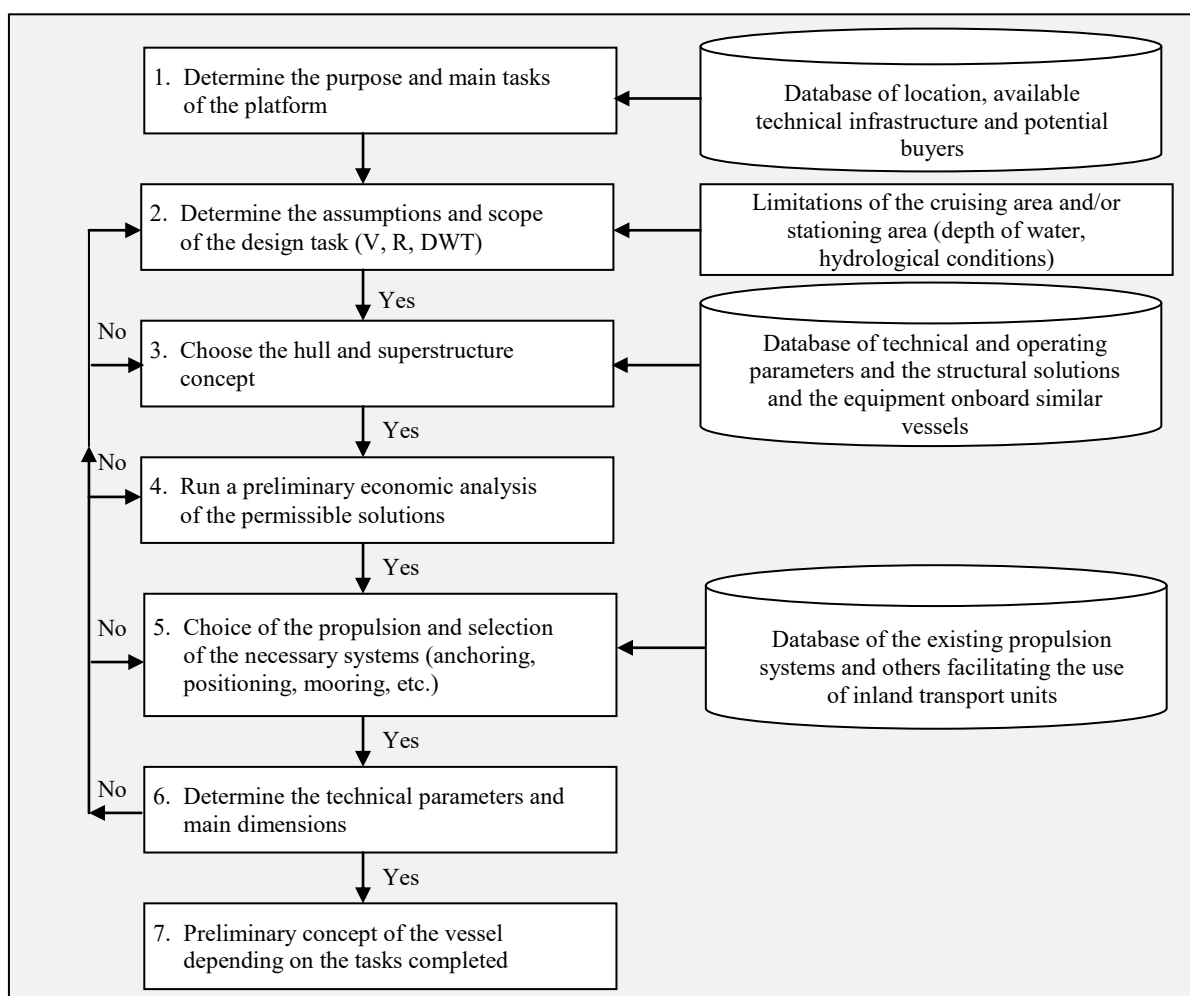


Figure 4. An algorithm of the choice of the concept of multipurpose inland residential platforms

2011). The benefit derived from using this solution is that the platform can be used on its own for various purposes if there is no use for its primary purpose at the given moment.

Taking the hull shape into consideration, it is the catamaran-hulled multipurpose residential platforms that will demonstrate better technical and operational parameters, such as buoyancy and stability, operating speed, better efficiency, different available deck areas and smaller draft.

The choice of propulsion will largely depend on the platform's purpose. A lack of the transport unit's own propulsion will mean smaller outlays on both its purchase and later technical upkeep (maintenance and repairs) and a larger deadweight tonnage, but at the same time the necessity for the owners to use external propulsion in order to change the mooring place.

Taking into account the conditions of inland navigation and the areas where mooring the multipurpose residential platforms concerned is allowed, three variants of their use can be discussed:

- Variant 1: A residential platform permanently situated at the wharf.
- Variant 2: A self-propelled mobile residential platform.
- Variant 3: A mobile residential platform without its own propulsion.

Individual stages of the analysis and choice of the concept of multipurpose inland residential platforms are shown in Figure 4.

The functioning of multipurpose inland residential platforms at a specific location will first of all be contingent on the following factors:

- the demand for the given sort of offer;
- the condition of the infrastructure and suprastructure of the inland harbors and marinas;
- the parameters and properties of inland waterways;
- the existence of appropriate legal regulations, etc.

The choice itself of the multipurpose inland residential platform depends on numerous factors, such

as functional, technical or economic ones, which determine, for instance, the platform's shape, basic technical and operational parameters, or the type of propulsion.

The questionnaire study analysis on the evaluation of the societal interest in using inland residential platforms

An important issue in determining the concept of residential platforms is understanding the expectations of the local community. Since the operation of this type of construction in Poland is not very common, and there is no information about the attractiveness of this type of offer, it is therefore necessary to determine the state of knowledge and social expectations. For this purpose, a questionnaire survey in three cities above water: Szczecin, Wrocław and Bydgoszcz, which have the ability to use various proposed concepts, has been conducted. The questionnaire study was used to assess public awareness of the viability of residential platforms in selected cities.

The questionnaire was open to the public and due attention given to the answers from different age groups. It was a one-off questionnaire, unattended, direct and online. It was performed once; the participants received questionnaires directly from the interviewer, returning them after completion, without having the ability to consult the interviewer. In the case of the online questionnaire, they were sent electronically to the participants. An online survey was chosen due to the fact that studies were carried out in various selected cities, which allowed for easier contact with the respondents. The questionnaire used closed questions. The survey was conducted in August 2016. There were 253 participants who took part in the questionnaire, which contained six questions. Table 2 shows the results of the survey.

The largest percentage (57%) of participants were people between 30 and 60 years old. Thus, it is

Table 2. Results of questionnaire survey

No.	Question	Answers		
		Yes	No	No opinion
1.	Are there some residential platforms in your city?	17	178	58
2.	Have you ever seen this type of construction in different towns?	140	111	2
3.	Would you consider the presence of platforms as attractive for the city's image?	156	81	16
4.	Would you like to make use of living possibilities on the water seasonally as a tourist?	189	52	12
5.	Would you like to live on the residential platform all the time?	48	160	45
		Up to 30	31–60	above 60
6.	What is your age?	86	144	23

possible to create new offers, which will be adapted to the needs of society. This is a population that can direct their interest towards living on the water and is able to undertake this type of investment.

The conducted questionnaire survey showed that:

- society does not have adequate knowledge of this type of residential construction;
- society has a very positive view of this type of housing;
- over half of the participants considered that the presence of residential platforms is appealing to the city's image;
- society would prefer living on the water seasonally, for tourism, to all year round.

Conclusions

Initiating the use of multipurpose inland residential platforms is one of the available directions for spatial development, and an alternative to the typical residential construction solutions in waterside towns and cities. Depending on specific needs, such platforms will play various roles and by taking advantage of the existing conditions, they will provide an opportunity for the development of tourism, residential construction, and civil and hydraulic engineering.

Initiating the use of multipurpose inland residential platforms may contribute to:

- 1) activating and expanding harbors, marinas and their surrounding areas;
- 2) modernizing and revitalizing waterside towns and cities that have not yet utilized their potential;
- 3) promoting water tourism both in Poland and on the European scale;
- 4) facilitating accommodation for uniformed services, first of all the army or the border guard, due to their constant deployment;
- 5) supporting local government authorities in emergencies by providing temporary accommodation to those in need.

The concept of multipurpose inland residential platforms as shown in this paper is but a preliminary

outline of the idea and its main assumptions. Further studies should focus on:

- determining the requirements and guidelines for designing residential floating platforms;
- developing concept designs of the possible variants of floating platforms, easily adaptable to changing assumptions and scopes of operation;
- exploring the analytical relationships, taking into account the actual conditions of operating such vessels;
- establishing the procedures to be applied at the project implementation stage and their technical standards based on the existing standards and legal regulations.

Acknowledgments

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Assumption of state policy concerning inland waterways in Poland

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Key words: inland waterways, water transport, infrastructure inland waterways, technical condition, state policy, perspective

Abstract

Despite the assumption of government documents to support inland waterways, degradation of the technical condition of waterways and depreciation of fleet ship-owners is actually occurring. At the marginal importance of inland waterway transport policy, the government also shows a negligible share of the transport sector in the use of EU funds. The Sectoral Operational Programme Transport 2004–2006 does not provide for EU funds to co-finance investments for inland waterway transport. Small funds for this purpose were obtained only in the framework of the Operational Programme Infrastructure and Environment 2007–2013. It should be noted, however, that during the control of the Ministry of Transport, Construction and Maritime Economy – in cooperation with the National Water Management – efforts were led to ensure that the new 2014–2020 financial perspective for the tasks related to the improvement of infrastructure of inland water transport were granted before aid. Against the background of European trends in developed countries of the European Union (EU), the Polish inland waterways are not important in the transport of goods, but instead the transport of persons confined to tourism and local – to supplement the motor transport infrastructure (river ferries). For many years Poland has experienced a decrease in both freight and inland waterways, as well as in their participation in all transport modes. The aim of this article is to assess the activities of government administration in the performance of statutory tasks related to the development and operation of inland waterway transport in Poland.

Introduction

Poland is characterized by a relatively high-density network of waterways. In Poland, every 1000 km square there are 11.6 km of navigable waterways, compared to the EU-average of 9.3 km / 1000 km square. Countries with higher density ratios are: The Netherlands (121.6 km), Belgium (50.2 km), Finland (23.7 km), Germany (18.6 km), Hungary (15.5 km) and Luxembourg (14.2 km). Cargo volumes are reflected in the technical condition of the water transport infrastructure subsystem and its role in the transport system within the country. Poland, despite a well-developed network of waterways, has a very low share of cargo river transport in total land freight – approx. 0.1%, while the share of inland waterways in the individual EU countries stands at

34.7% in The Netherlands, 5.8% in Belgium, 12.6% in Bulgaria, 12.3% in Germany.

The use of inland waterways first requires change in the approach of navigation in Poland – to be both innovative and comprehensive. The inclusion of the river in the European system of waterways is a project of the waterway Danube–Odra. The combination of the Baltic and North Sea with the Black Sea and the Mediterranean basin, is the largest marine project in Central Europe. Connecting the above navigation line with the wide path from the far east, it is a project of European importance, because all European countries and non-European countries will use this connection – from Japan, through North Korea and Noon, China, Mongolia, Russia and Ukraine. The time of return rail freight will be reduced by 1/3 compared to the sea route's used today (from about

30 days to 10 days). According to preliminary calculations, it is possible to transport in both directions by rail transport, 750 thousands of containers and other goods annually. Completion of the Odra's railway line, route S3 and the future Odra–Danube channel would make the port in Szczecin and river ports on the Odra River comparable to Hamburg and Rotterdam in terms of tonnage transported (Ogólnopolski Klaster Innowacyjnych Przedsięwzięć, 2015).

The most significant external conditions of the development of water transport should include the current and future role of inland waterways for European transport policy. Economic development of the European Union, as well as the intensification of economic exchange associated with the enlargement of the EU, caused an increase in demand for transport. Current trends indicate a preference for motor transport, being the fastest and most flexible element, adaptable to changes in transport needs (and directions). Therefore, an uncontrolled development of transport would lead to a significant increase in the workload of the road network, as well as increased pollution and the adverse circumstances to paralysis of communication. This situation points to the need to take measures to reduce further the negative impact of the development of road transport on the environment, among others, by promoting the development of systems more friendly to the environment. These actions are aimed at reconciliation of the above trends with constraints in the development of transport and going beyond transport policy. As stated in "White paper – European transport policy – time decision making" (White Paper. European transport policy for 2010: time to decide. Luxemburg 2001) in new conditions, transport policies should be part of an overall strategy of sustainable development, including, in particular:

- economic policies, in particular the changes in the production process, which determine the volume of demand;
- policy of spatial land development, especially cities, aiming to avoid an excessive growth in the demand for transport;
- social and educational policy, including a better organisation of work and learning to allow restriction of the traffic peaks (e.g. during weekends) (Adameczyk, 2011).

The development of inland water transport

The development of inland water transport can be one of the ways to solve such problems of contemporary transport policy (Wojewódzka-Król, 2006):

- to achieve sustainable transport development;
- meeting the growing demand for transportation in the territorial restrictions which are a barrier to the development of transport infrastructure;
- increasing the availability, in terms of congestion, lack of connections and bottlenecks in the trans-European transport network, which faces financial constraints and barriers on existing zoning.

Water transport is characterized by many features which predispose it to play a much more important role in the transport system of both goods and passengers. Inland waterway transport is one of the cheapest and most environmentally friendly branches because of, inter alia:

- relatively low power consumption;
- low emissions of air pollutants;
- relatively low water pollution;
- the ability to significantly reduce congestion on the roads as a result of the adoption of freight road transport;
- the lowest external costs.

To strengthen the position of inland waterway transport in the system of goods transport requires, first and foremost the introduction of adjustments to new conditions, consisting mainly of the:

- development of combined transports;
- inclusion of inland waterways in the development of coastal transport;
- development of sea-river transport;
- construction of logistics centres in river ports;
- identification of market niches in the new environment, and strengthening the position of this sector in the current application.

The possibility of a solution, or at least alleviation of the fundamental problems of European transport, through the use of inland waterways, is a determinant support for the development of this sector in the European Union. Supporting this manifests itself mainly in:

- the commitment to improving waterway infrastructure;
- creating favourable conditions for the development of reloading ports;
- lower fuel prices for shipping companies;
- other forms of assistance provided to this branch of transport in selected countries.

Meeting future transport needs in an environmentally friendly way will require overcoming current problems of inland water transport, as well as supporting the development and promotion of its advantages as a modern mode of transport. Reasons of such aid for inland waterway transport are primarily:

- the great potential of this branch of transport;
- the lack of effective instruments for the internalisation of external costs, which would effectively compete with other modes of transport;
- inadequate efforts on the development of inland waterways connected with the mistaken belief that the branch will not be able to meet new challenges;
- the need to implement new technologies determining successful integration of the inland water transport to service transportation needs that require coordinated action (Adamczyk, 2011).

The technical condition of inland waterways in Poland

The operating parameters of inland waterways do not meet the requirements set out in the Regulation of the Council of Ministers of 7 May 2002 on the classification of inland waterways. The regulation was decided that for waterways or sections on which there is a variable water level the actual value of the draft of the vessel or pushed convoy, relative to a fixed parameter classification, should not be less than the value of immersion occurring during 240 days, or furthermore, in the multi-year average (multiannual period) (Regulation, 2002, § 4 para. 2). The most important difficulties of shipping are insufficiently deep fairways, the operation of bridge parameters (both road and rail) and the often repeated failure of locks and weirs, as well as long periods of interruption of navigation (due to freezing, and high water).

The existing condition of the waterways was the main reason for not allowing Polish accession to the Agreement on Main International Waterways meanings (AGN), prepared by the Economic Commission for Europe – United Nations on 19 January 1996. The accession of Poland to the AGN agreement was the subject of studies at the turn of 1997–1998. Due to the very high cost of road reconstruction of water – more than 90 billion PLN, the Minister of Finance did not approve the signing of this agreement. Also, the Minister of the Environment refused to sign the Agreement on the grounds of a significant intervention in the river valleys and rivers. It should be mentioned that according to information from MTBiGM, the AGN agreement has not been signed or is not ratified by 21 European countries, including 14 member states of the EU (NIK, 2014).

The government's actions have not led to an inhibition of regression in inland navigation. For years, despite the Government's declaration of an increase

in the importance of inland waterway transport, documents governing the transport policy of the State show that the size of the inland water transport freight, as well as their share of the total freight of all modes of transport are shrinking. The main reason is the progressive degradation of the technical condition of inland waterways. There was no renewal of the fleet for freight inland water transport and furthermore most of the inland waterway fleet is depreciated. It should be noted that the age of the fleet far exceeds the standard period.

The length of the inland waterway network in Poland in 2014 remained at a similar level as in the previous year and amounted to 3655 km, of which 2417 km was regulated river navigable, 644 km – canalised sections of rivers, 336 km – channels and 259 km – lake navigable. The length actually operated by shipping was 3387 km (92.7%) navigable waterways. Adjusting the size of vessels and waterways is the main factor determining the effectiveness of inland waterway transport. Road requirements of international importance (classes IV and V) in 2014 were fulfilled in Poland at 5.9% of the length of waterways (214 km). The share of roads in this class, providing the parameters necessary for modern shipping has not changed since 2007 from the total length of waterways in Poland. The rest of the waterways have regional importance class I, II and III, with a total length in 2014 of 3441 km (94.1% of the total length of waterways) (GUS, 2015).

Table 1 shows operated inland waterways in 2014 in Poland.

Table 1. Operated inland waterways in 2014

Specification	Navigable river regulated	Channelled sections of rivers in kilometres	Channels	Lakes navigable
Total	2174	620	334	259
Regional roads				
Ia	664	101	168	54
Ib	608	137	–	–
II	691	106	106	168
III	115	207	47	28
International roads				
IV	–	14	–	–
Va	–	55	–	–
Vb	97	–	14	10

Inland waterway fleet and transportation

In 2014 the number of fleet in inland waterway transport in Poland (tugs and tugs) totalled 207 units a decrease of 1.0% compared with the previous year. Compared with 2013, this has increased the number

of self-propelled barges – up to 79 pcs. (11.3%) and the number of barges without their own power – up to 504 pcs. (0.8%). While the number of passenger ships decreased – up to 99 pcs. (3.0%). In the structure of generic fleets, barges dominated by the units used in the sets being pushed. For this type of transport in 2014, this represented 86.4% of the total fleet and transported 6166.5 thousand tons of cargo (80.8% of all goods transported by inland waterways). In the group of fleet barge, vessels of smaller design parameters prevailed, which require lower standards of technical infrastructure (GUS, 2015).

Figure 1 shows the structure of barge fleet inland waterway by groups of capacity in 2014.

A large part of the inland waterway fleet depreciated and required restoration as its age far exceeded the standard period of use, and the operation possible due to constant modernization. According to data for 2014, of most operated pushers (74.2%), almost half of the bar to push (48.2%) and all self-propelled barges were produced in the years 1949–1979.

Figure 2 shows age structure of fleet inland waterway in 2014 in Poland.

Inadequate management of navigable roads in Poland, both in terms of character (“Channelized” River, flowing freely, channels) and navigational parameters (dimensions, depth and width of the trail, the height of bridges) affected the specificities of inland waterways and played a marginal role in the Polish transport system. The share of inland

waterway transport in total freight transport in the 2000–2014 period decreased from 0.8% to 0.4%.

In 2014, inland waterways transported 7629 thousand tons of cargo and carried 778.5 million tkm of transport work. In comparison with the previous year this represents an increase of freight expressed in the number of transported tonnes (51.2%), as well as an increase in the size of the transport (1.4%). The largest increase in shipped tonnes of cargo (125.3%), while increasing the size of transport work (21.5%) occurred in the first quarter.

Figure 3 shows transport of goods by inland waterways by quarter.

In 2014, the average distance of transport for 1 ton in international traffic amounted to 253.4 km (in 2013 – 252.6 km), and in domestic transport – 14.5 km (in 2013, 25.6 km). The large average distance in international transport is clear from the dominant share of freight transport on the Western European waterways.

Compared to 2013, there was an increase of domestic carriage by 116.8% to 4833 thousand tonnes (mainly cargo from group aggregates, sand and stone), with an increase in traffic of 22.9% to 70.0 million tkm. Such a significant increase in traffic was associated primarily with the participation of inland waterway transport in the Modernization of Wrocław Floodway System project.

In 2014, international traffic amounted to 2,796 thousand tons of cargo (0.7% less than in the previous

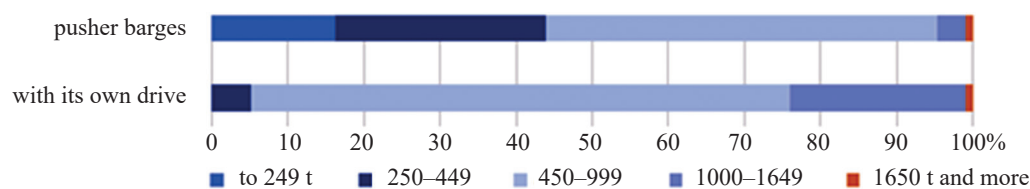


Figure 1. The structure of barge fleet inland waterway by groups of capacity in 2014

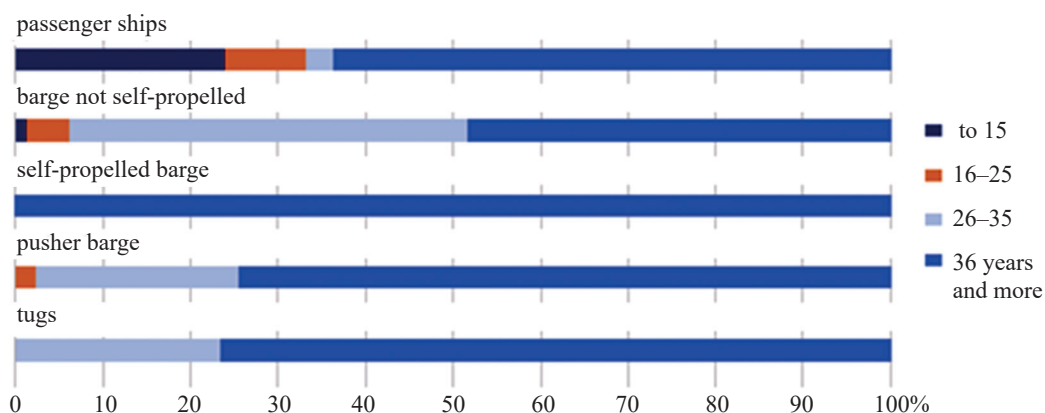


Figure 2. Age structure of fleet inland waterway in 2014

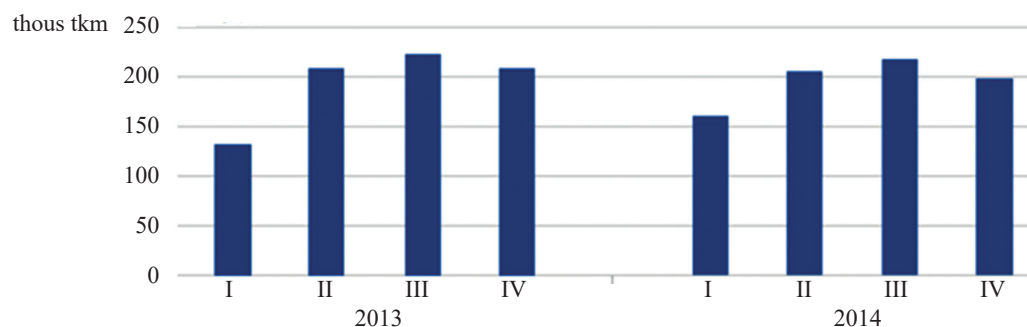


Figure 3. Transport of goods by inland waterways by quarter

year), which accounted for up to 36.6% of all cargo transported by Polish ship-owners. The volume of traffic between foreign ports decreased by 3.9%, and their share in total international traffic transport decreased from 70.2% in 2013 to 67.9% in 2014. Levels of imported cargo were also lower (40.7%), while there has been an increase in freight exports (16.6%). The main direction of export by inland waterways (representing 29.2% of total international transport) was to Germany. The share of transport in this relationship amounted to 92.0% of total exports on the waterway (GUS, 2015).

Conclusions

Inland water transport is seen in Poland, often as a branch, whose development is not important for the Polish transport system. This is because a low share of this branch of transportation needs is wrongly identified as having marginal importance in the transport system. This is at odds with the European policy on the sustainable development of transport. The present idea of shaping the sustainable development of transport assumes comprehensive measures in all areas and transport sectors, not just those which have the dominant approach. Sustainable transport policy in the EU assumes the development of the shipping industry to be environmentally friendly wherever it is possible to reduce the external costs of transport.

The development of inland water transport in the European Union is one of the ways to solve such problems of the modern transport policy to:

- be a sustainable transport development;
- meet the growing demand for transport with territorial disadvantages, which are a barrier to the development of transport infrastructure;
- increase the availability, in terms of congestion, bottlenecks in the trans-European transport network and the lack of connections, whose elimination is associated with financial constraints and barriers in existing zoning.

The internalisation of the external costs of transport would generate considerable advantages to inland waterway transport over the other branches. However until internalisation, this branch, must to rely on various forms of support. Supporting the development of inland water transport in the EU is associated primarily with small harmful effects on the environment. Although not without significance, there also exists advantages to this mode of transport, including in particular:

- a comprehensive nature for the development of waterways to benefit all areas of the economy;
- essentiality to the operation of seaports, creating beneficial connections with the hinterland, and allowing an increased capacity of sea ports.

The development of inland water transport requires many difficulties to be overcome associated with problems of shipping companies, such as a reluctance of potential customers who see it quite traditionally, to recognise the new opportunities and benefits associated with it.

Problems of the development of this branch in Poland are similar to those in other EU countries, but they are of a much larger scale. Unfortunately, this sector has not found a proper place in the current policy of transport development, which has led to a very difficult situation. Inland water transport is a little known branch for potential users.

The role of inland waterways in Poland, as a result of serious irregularities in the process of its development, does not correspond to modern tendencies. Inland waterway transport in relation to the most favourable period fell by more than 10 million tonnes, including national transport by more than three times. Participation of this branch in the seaports service decreased four times, despite the demand for this type of transportation in relation, for example, to Szczecin – Berlin and the fact that Berlin's favourable location in relation to the port gives it an advantage over Hamburg, to which the distance is almost two times greater (Wojewódzka-Król, 2014).

Currently, freight transports greatest challenges concern the modernization of transport infrastructure, rail and inland waterways. The low standard of service stations and underspending of water transport can become very expensive for seaports.

Funds spent on inland waterway transport investment would enable the development of this branch, and also prevent decapitalisation of existing infrastructure. This policy would lead ultimately to an improvement in the condition of waterways, and thus bridge the disparities in the development of inland water transport, rail and road.

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Miscellaneous

The phenomenon of increasing concentration of tourism in Polish seaside regions

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Key words: port cities, tourist traffic, regional development, seaside regions, intensity of tourist traffic, forecasts, extrapolation of trends

Abstract

The aim of this article is to point to the phenomenon of increasing concentration of tourism in the Polish seaside regions. The study involved four port cities, located in two seaside voivodeships: West Pomeranian (Szczecin, Świnoujście) and Pomeranian (Gdańsk, Gdynia). They are cities where seaports of major importance for the national economy are located. The analysis of tourist traffic in these cities covers the years 1995–2014. This analysis formed the basis for the forecast to 2020. The results of extrapolation of trends are presented in the figures. Moreover, the procedure employed and structure of the article were adapted to the aim of this work.

Introduction

The impact of tourism on regional development is multifaceted. Tourist reception areas are subject to changes, which result from the development of their tourist function. These transformations are of economic, social, cultural and spatial nature. The consequences of tourism development are felt throughout the country, voivodeships (provinces), as well as single towns or cities and depend on the concentration of tourist traffic.

Tourist traffic is called the temporary migration of people outside the place of their permanent residence, resulting from socially conditioned needs with various motivations (Kurek & Mika, 2008, pp. 13, 40–42). It can also be described more broadly as the general phenomena and effects of spatial movement of people during tourist trips (Mazurski, 2006, p. 66). In order to fulfill the tourist's needs, the tourist must move to a specific place, where the elements of tourism supply are located. Therefore, tourism demand measured by tourist traffic is characterized by mobility and concentration in space.

Tourism is directly associated with transport. It is necessary for tourists to reach their destination and navigate within the visited region. Transport services belong to basic tourist services. They are considered to be a dynamic factor in the development of tourism and its support (Gaworecki, 2010, pp. 291–292). On the other hand, the region attracts tourists and generates a demand for transport services. In addition, travelling by some means of transport is considered as a tourist attraction, e.g. cruising, small-gauge train, historic tram, etc.

There are different criteria that are applied by a tourist when choosing means of transport during a trip. In addition to financial, technical and security aspects, the transport accessibility to region is very important. The transport accessibility is not only the grid of transport links inside and outside the region, it is also the set of facilities necessary to transport operations in a given area that is called transport base of tourism (Pawlusiński, 2008, p. 166). The better the transport base of tourism, ensuring transport accessibility to a specific area, the larger its attractiveness as a destination. For these reasons, progress

in the transport field has influence on the development of tourism.

New solutions for transport stimulate an increase in carrying capacity, in both quantitative and spatial terms. They also improve the comfort of traveling. These aspects are very important in the development of port cities, which are also characterized by significant tourist traffic. The maintenance of the existing volume of tourist traffic in these areas, and its increase, are essential in the light of the development of the whole regions.

Among other things, an analysis and assessment of tourist traffic in port cities and seaside regions in Poland is useful to determine the basic conditions of tourism development. Effective stimulation of the development of these regions, taking into account the substantial impact of tourism, requires many operations that should be properly planned and coordinated. Their range is very wide and varied. Successful support for tourism requires action, *inter alia* in terms of the transport accessibility, tourism planning, promotion, education, security, regional and tourism policy, as well as scientific research.

Building, modernizing and evolving the passenger terminals in seaports with particular emphasis on infrastructure and logistics support of cruise ship passengers and tourists strongly affects the development of tourism in seaside regions in Poland (Christowa, 2010, p. 189); however, decisions on this type of investment should be supported by expert opinions and scientific reports. Such reports should provide predictions about the evolution of phenomena affecting the future development of seaports, port cities and seaside regions. It is necessary to take into account the scope of the impact of tourist traffic on these areas. For this reason, knowing the strengths of the region is a prerequisite for an efficient development.

Main aim and research methods

The aim of this article is to point to the phenomenon of increasing concentration of tourism in the Polish seaside regions, with particular emphasis on port cities (Szczecin, Świnoujście, Gdańsk, Gdynia). These are cities where seaports of major importance for the national economy are located. Particular attention is paid to the role of tourist traffic in the development of these cities and all regions.

The study involved four port cities, located in two seaside voivodeships: West Pomeranian (Szczecin, Świnoujście) and Pomeranian (Gdańsk, Gdynia). These are the cities with powiat (county) rights.

Besides, Świnoujście has the status of seaside health resort. The analysis of tourist traffic in these cities covers the years 1995–2014 and formed the basis for the forecast to 2020. The prediction was made by extrapolating estimated trends (linear and parabolic). The results of these extrapolations are presented in the figures.

The source of statistical data was the Local Data Bank of the Central Statistical Office. Moreover, the study procedure and structure of the article were adapted to the aim of this work.

Analysis of results

In both Polish seaside voivodeships, much greater tourist traffic is evident in the areas located in the seaside compared to other zones. The seaside areas include six powiats of the West Pomeranian voivodeship and eight of the Pomeranian voivodeship; as illustrated in Figures 1 and 2.

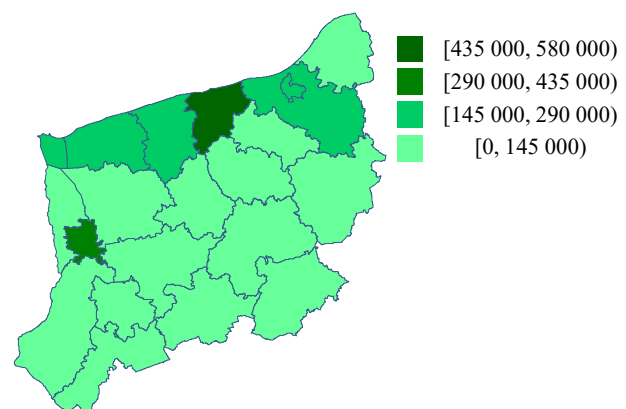


Figure 1. Diversification of tourist traffic in the powiats of the West Pomeranian voivodeship in 2014 by number of tourists staying at accommodation (author's findings, source: Central Statistical Office, 2016)

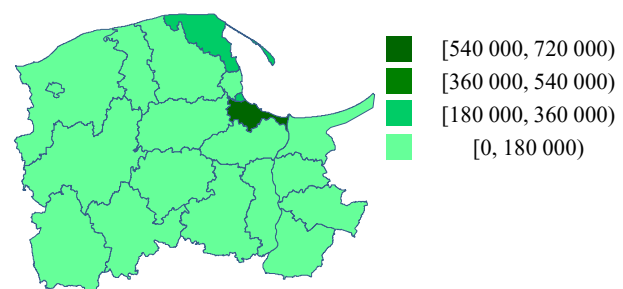


Figure 2. Diversification of tourist traffic in the powiats of the Pomeranian voivodeship in 2014 by number of tourists staying at accommodation (author's findings, source: Central Statistical Office, 2016)

In 2014, 27.63% of visitors staying in tourist accommodation in the West Pomeranian voivodeship

chose Szczecin (17.27%) or Świnoujście (10.36%). In the Pomeranian voivodeship, the share of Gdańsk and Gdynia is 32.73% and 5.32%, respectively, for a total of 38.05%.

In the years 1995–2014 the number of tourists accommodated in the establishments located in Świnoujście increased by 222.73%. Changes of this value are shown by the linear trend:

$$\hat{y}_t = 75\,128 + 5033t \quad (1)$$

[12 162]
[1015]

On this basis it can be said that during this period the number of tourists increased year by year by an average of 5033 (taking into account that, based on the standard error of estimate for this parameter, the error may be 1015 and is the value provided in the square brackets under the parameter). Unfortunately, this model matches empirical data only in 57.72% of cases (determination coefficient is $R^2 = 0.5772$), and the standard error of estimate amounts to 26,181 tourists. Both parameters of the model are statistically significant.

A better matching to the actual value has a parabolic trend with the following form:

$$\hat{y}_t = 101\,221 - 2084t + 339t^2 \quad (2)$$

[18 332]
[4021]
[186]

In this case, a higher coefficient $R^2 = 0.6463$ and lower standard error of estimate (24,640 tourists) were obtained. However, both variables t and t^2 have proved to be statistically insignificant.

Despite the imperfections of both estimated functions of the development trend, the number of tourists that will be accommodated in tourist facilities in Świnoujście until 2020 was predicted (using extrapolation of these trends) will be. The results should be considered as an estimate and are presented in Figure 3.

Significant annual increases in the number of tourists in the period 2012–2014 could have an impact on the moderate matching of the trend function with empirical data over the entire period. This is related with the change in the methodology of data collection by the Central Statistical Office. Since 2012 the tourist accommodation facilities have also included agro touristic lodgings and guest rooms. Unfortunately, the lack of information on such facilities at the powiat level makes it impossible to correct data by minimizing the number of tourists by those choosing this type of accommodation. On the other hand, all the tourists staying in accommodation facilities generate demand for goods and services in a particular area. It must be remembered that the forecast might

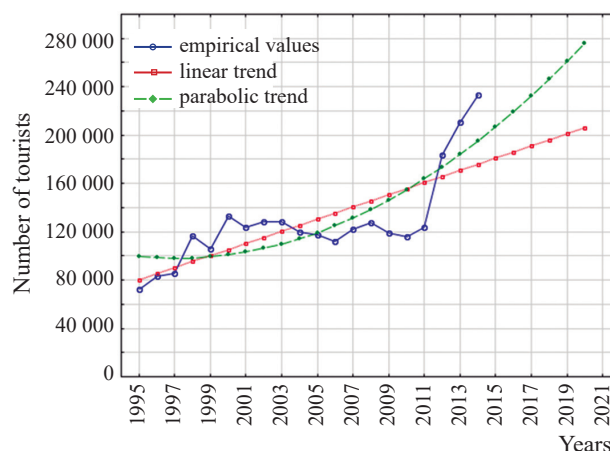


Figure 3. Tourists staying at tourist accommodation establishments in Świnoujście in the years 1995–2014 and forecast to 2020 (author’s findings, source: Central Statistical Office, 2016)

not be completely correct. Although it is difficult to currently identify the reasons that could lead to the situation, in which the tendency sudden collapses, it is likely that the growth rate may decrease, and not be as high as indicated by forecasts made on the basis of a quadratic trend extrapolation.

However, the number of tourists accommodated in the establishments located in Gdańsk in the years 1995–2014 increased by 169.64%. Changes of this value are shown by the linear trend:

$$\hat{y}_t = 197\,981 + 18\,623t \quad (3)$$

[27 409]
[2288]

On this basis it can be said that during this period the number of tourists increased year by year by an average of 18,623. This model matches empirical data in 78.63% of cases and the standard error of estimate amounts to 59,003 tourists. Both parameters of the model are statistically significant.

A much better matching to the actual value has a parabolic trend with the following form:

$$\hat{y}_t = 324\,425 - 15\,862t + 1642t^2 \quad (4)$$

[22 337]
[4899]
[227]

In this case, a higher determination coefficient $R^2 = 0.9478$ and lower standard error of estimate (30,023 tourists) were obtained. In addition, both parameters of the model are statistically significant.

Figure 4 shows the results of the prediction made on the basis of the extrapolation of the two estimated trends. Despite a marked increase in the number of tourists in the years 2012–2014 (also for reasons described above), both functions have a much better match to the empirical values than in the case of Świnoujście. Particularly optimistic is the forecast

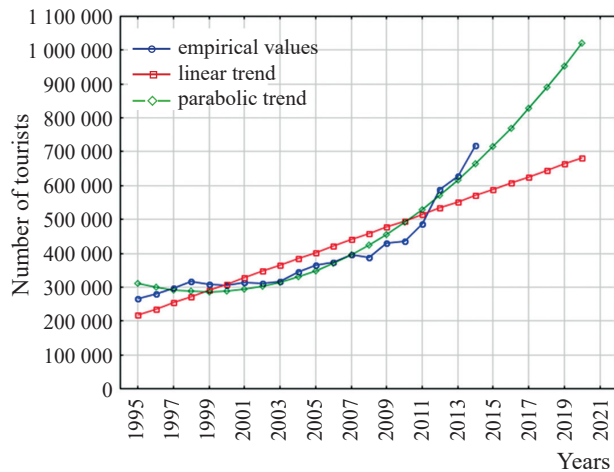


Figure 4. Tourists staying at tourist accommodation establishments in Gdańsk in the years 1995–2014 and forecast to 2020 (author's findings, source: Central Statistical Office, 2016)

based on the parabolic function, according to which the number of tourists staying in Gdańsk base in 2020 will increase by 42.06% (in comparison to the year 2014). It cannot be ruled out that this scenario will come true in the future.

The development trend of tourists accommodated in the establishments located in Gdynia in the years 1995–2014 has been described with the following linear function:

$$\hat{y}_t = 80\,049 + 2082 t \quad (5)$$

[2901]
[242]

and parabolic function:

$$\hat{y}_t = 72\,164 + 4232 t - 102 t^2 \quad (6)$$

[4107]
[901]
[42]

The number of tourists in this period increased by 55.58%. The adopted linear trend model matches the data in 80.41% of the instances considered. It assumes an annual growth of about 2082 tourists and the standard error of estimate amounts to 6245 tourists. A slightly better matching to the actual data is shown by the parabolic function ($R^2 = 0.8555$, the standard error of estimate 5520). All parameters of models (5) and (6) are statistically significant.

The results of the forecasts prepared on the basis of the extrapolation of trends are shown in Figure 5. The prediction based on the parabolic function is pessimistic, because it assumes a decline in the number of tourists. More optimistic is the forecast based on the linear trend, according to which the number of tourists staying in Gdynia in 2020 will increase by 14.87% (in comparison to the year 2014).

In the years 1995–2014 the number of tourists accommodated in the establishments located in

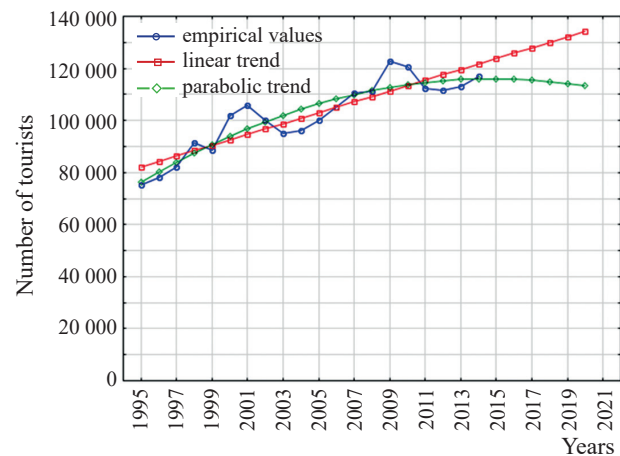


Figure 5. Tourists staying at tourist accommodation establishments in Gdynia in the years 1995 – 2014 and forecast to 2020 (author's findings, source: Central Statistical Office, 2016)

Szczecin increased by 24.54%. It was the smallest percentile growth among the four port cities considered. Also, the greatest fluctuations in the number of tourists is observed in Szczecin, especially during the first part of the time frame considered (1996–2003). To smooth out these fluctuations, the data from the years 1996–2003 were considered outlying observations (these observations may result in disturbance of the result of the analysis of time series (Masłowska, 2015, pp. 20–21)). This was confirmed on the basis of the scatter diagram of dependent variable and analysis of residuals. If outlying observations are deleted, it is necessary to estimate the missing data (Zeliaś, Pawełek & Wanat, 2003, p. 26). For this purpose a simple moving average method was used (Machowska-Szewczyk, 2007, p. 163) to replace each empirical value from the years 1996–2003 with an average of five neighboring points (years). For the year 1996 only, the average was taken on three points, due to missing data.

After smoothing out the time series of the number of tourists accommodated in the establishments located in Szczecin, changes of this value are shown by the linear trend:

$$\hat{y}_t = 299\,872 + 4170 t \quad (7)$$

[9572]
[799]

In spite of the smoothing, this trend matches the modified empirical data only in 60.20% of cases. Both parameters of the model are statistically significant. The parabolic trend did not give a significantly better matching ($R^2 = 0.6491$); however, both variables t and t^2 proved to be statistically insignificant.

Figure 6 shows the results of the prediction made on the basis of the extrapolation of the

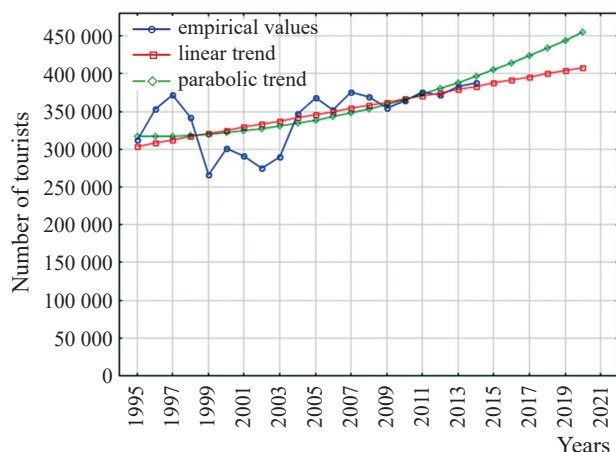


Figure 6. Tourists staying at tourist accommodation establishments in Szczecin in the years 1995–2014 and forecast to 2020 (author’s findings, source: Central Statistical Office, 2016)

estimated trends. The results should be considered as an estimate. According to the forecast based on linear trends (7), the number of tourists staying in the Szczecin base in 2020 will increase only by 5.21% (in comparison to the year 2014). More optimistic is the forecast based on the parabolic function (17.32% increase).

In addition, an analysis of variability in the intensity of tourist traffic was carried out in the four port cities. The intensity of tourist traffic expressed with Schneider’s rate reflects the number of tourists accommodated per 100 inhabitants (Warszyńska & Jackowski, 1979, p. 69).

The development trend of the tourist traffic intensity growth rate in Świnoujście in the years 1995–2014 has been described with the following functions:

$$\hat{y}_t = 172.97 + 12.81t \quad (8)$$

[28.73] [2.40]

$$\hat{y}_t = 172.97 + 12.81t \quad (9)$$

[28.73] [2.40]

Both estimates moderately explain changes in the intensity of tourist traffic in Świnoujście. The determination coefficients R^2 amount to 0.6132 and 0.6663, respectively. In addition, in the case of a parabolic trend (9), both variables t and t^2 are statistically insignificant.

The results of the extrapolation of both trends are presented in Figure 7. According to the forecast prepared on the basis of function (9), in 2020 about 655 tourists (per 100 inhabitants) will choose to sleep in this area. Due to the low overall matching of the model to the empirical data, this value is only an estimate; however, assuming that the current

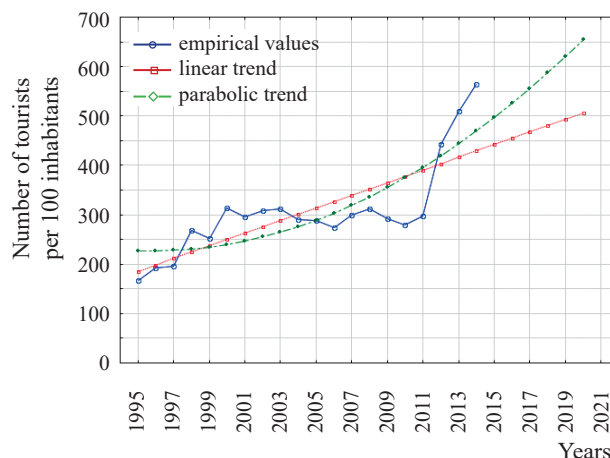


Figure 7. Number of tourists staying at tourist accommodation establishments in Świnoujście per 100 inhabitants in the years 1995–2014 and forecast to 2020 (author’s findings, source: Central Statistical Office, 2016)

slight downward trend in the number of inhabitants remains at a similar level and the increase in the number of tourists continues, this scenario is likely to happen.

The evolution of the tourist traffic intensity rate in Gdańsk in the years 1995–2014 is described as the following functions:

$$\hat{y}_t = 42.83 + 4.07t \quad (10)$$

[5.83] [0.49]

$$\hat{y}_t = 69.69 - 3.26t + 0.35t^2 \quad (11)$$

[4.76] [1.04] [0.05]

The adopted model of a linear trend (10) for 79.52% of the experiments explains the variability of the tourist traffic intensity rate in this period. It assumes that it grew year by year by an average of about 4 tourists per 100 inhabitants. A much better matching to the empirical values is shown by the parabolic function ($R^2 = 0.9496$, the standard error of estimate 6.40). All parameters of the models (10) and (11) are statistically significant.

The results of the forecasts prepared on the basis of extrapolation of trends are shown in Figure 8. Assuming the current growth rate of the number of tourists choosing to sleep in this area, according to the forecast that comply with the function (11), in 2020 this rate will reach a value of about 222 tourists per 100 inhabitants (including an error of about 6 tourists). This prediction is more optimistic; however, this value is lower than in Świnoujście. This is due to the fact that about 11 times more people live in Gdańsk.

Growth rate development trend of tourist traffic intensity in Gdynia in the years 1995–2014 has been described by the following linear function:

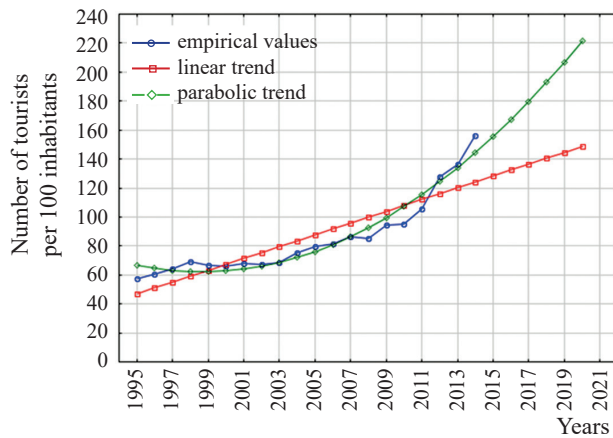


Figure 8. Number of tourists staying at tourist accommodation establishments in Gdańsk per 100 inhabitants in the years 1995–2014 and forecast to 2020 (author's findings, source: Central Statistical Office, 2016)

$$\hat{y}_t = 31.39 + 0.88t \quad (12)$$

$\begin{matrix} [1.14] & [0.10] \end{matrix}$

This model matches empirical data in 82.42% of cases and the standard error of estimate amounts to 2.46 tourists per 100 inhabitants. Both parameters of the model are statistically significant. Not much better matching to the actual value has a parabolic trend ($R^2 = 0.8594$). However, variable t^2 has proved to be statistically insignificant.

The results of the extrapolation are presented in Figure 9. According to the forecast prepared on the basis of function (12), in 2020 about 54 tourists (per 100 inhabitants) will choose to sleep in this area.

On account of the fact that the great fluctuations in the Schneider's rate is observed in Szczecin, the data from the years 1996–2003 were considered outlying observations. This was the same finding as in the case of the number of tourists staying in tourist accommodation solutions. The same method was

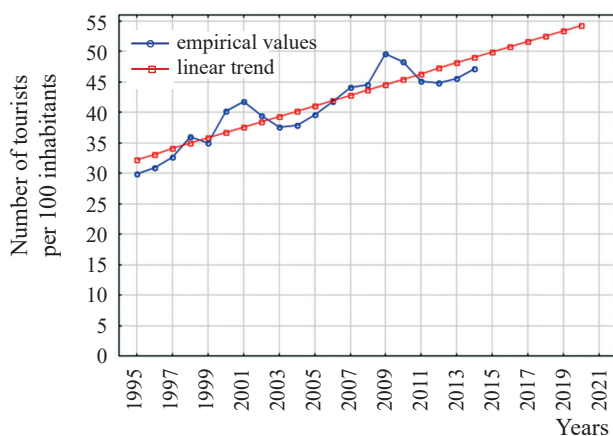


Figure 9. Number of tourists staying at tourist accommodation establishments in Gdynia per 100 inhabitants in the years 1995–2014 and forecast to 2020 (author's findings, source: Central Statistical Office, 2016)

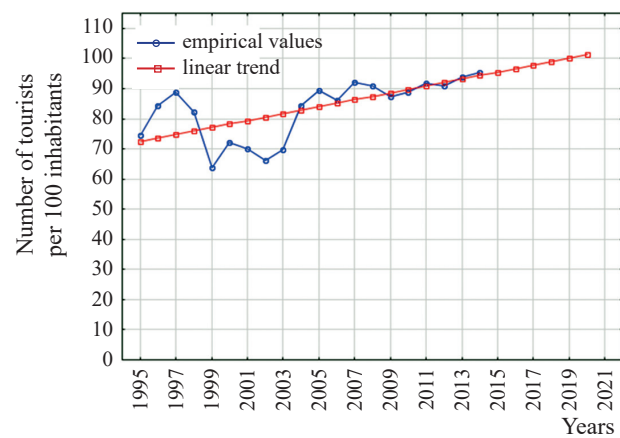


Figure 10. Number of tourists staying at tourist accommodation establishments in Szczecin per 100 inhabitants in the years 1995–2014 and forecast to 2020 (author's findings, source: Central Statistical Office, 2016)

applied in order to smooth out these fluctuations. After this, the evolution of the tourist traffic intensity rate in Szczecin in the years 1995–2014 is described as the following linear function:

$$\hat{y}_t = 71.34 + 1.15t \quad (13)$$

$\begin{matrix} [2.36] & [0.20] \end{matrix}$

Despite the smoothing out of fluctuations, this model only explains the variability of the tourist intensity rate in this period in 65.44% of cases. Both parameters of the model (13) are statistically significant. The parabolic trend ($R^2 = 0.6878$) does not give much better matching; however, both variables t and t^2 have proved to be statistically insignificant.

Figure 10 shows the results of the prediction made on the basis of the extrapolation of the estimated model. The results should be considered as an estimate. According to the forecast that comply with function (13), in 2020 this rate will reach a value of about 101 tourists per 100 inhabitants (including an error of about 5 tourists).

Conclusions

Both Polish seaside voivodeships are characterized by increasing tourist traffic. But its concentration is spatially differentiated. Four port cities play an important role in the size and intensity of tourist traffic.

Compared to the results of the 1995 survey, the number of tourists staying at tourist accommodation establishments has increased in all four port cities in 2014. In the years 1995–1998 the highest number of tourists chose to sleep in accommodation establishments located in Szczecin. But Gdańsk has been the leader in terms of this number since the year 1999.

The biggest growth dynamics of number of tourists staying at tourist accommodation establishments during this period has also been observed there.

The highest intensity of the tourist traffic is in Świnoujście. Taking into account the possible effects associated with the increasing congestion in the health resort, it is hard to say whether this is optimistic. Certainly it requires planning relevant activities within the local and regional policy.

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A graphical model to determine the influence of surface currents on small objects immersed in water

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Key words: estimating survivor location, search survivor movement, object searching, search planning, trajectory prediction, search and rescue, graph theory, hydrodynamic models

Abstract

This paper proposes a model of the interactions between surface currents and small, moving objects. These objects are immersed in water so that the part extending above the water is no larger than a human head. These interactions are defined as the weighted-directed graph. The basis for determining the edge weights are the directions of the surface currents. The speeds of these currents are used to calculate the time of moving objects. According to the modelling method of the surface-current influence on small objects, presented in this paper, it is possible to implement an application supporting search-and-rescue-operation planning. This method can be used to locate small objects, such as survivors, when planning search-and-rescue operations. Thus, the routes of these objects moving together with surface-water masses can be predicted using this method.

Introduction

The International Aeronautical and Marine Search and Rescue Manual (IAMSAR, as amended) (ICAO & IMO, 2013) recommends the computing of a search area where survivors may be located by finding two datum positions based on the total water current and leeway from the last-known position. However, this method in coastal waters may indicate an incorrect search area. This error is due to the fact that the method takes into account sea currents, which are the main, large-scale flow of ocean waters caused by, among others, large-scale winds. Therefore, the method presented in this manual is based on the natural phenomena occurring in large water reservoirs with characteristics of ocean basins. IAMSAR (ICAO & IMO, 2013) recommends using data from short-term, reliable weather forecasts in coastal areas. These forecasts can be generated by hydrodynamic numerical models with high resolution. The method for describing the surface-current influence on small objects presented in this paper can narrow down the search area of these objects to

restricted waters, e.g., in coastal areas. Moreover, this approach can minimize the time required to locate a search object.

Hydrodynamic numerical models generate discretization grids with nodes of associated data, including information on their location, the dynamics of the marine area (currents, waves), and hydrological parameters (water temperature, salinity, sea level). In this paper, the location data are associated with the nodes of the considered grid by using geographical coordinates. In addition, directions and speeds of sea currents are determined. The discretization-grid nodes might be represented within a certain data structure. We can move between different grid nodes. The movement from one node to another is carried out along a certain route.

We describe the movement of small objects immersed in water based on the part extending above water level no larger than a human head. The movement of such objects in water is caused by surface currents. We consider currents in the layer down to the depth of one meter. Such objects will move, following the directions of surface currents.

We will establish a radius of a circle encompassing the grid nodes. The object will be able to move from the current node only to these nodes. We assume that the object will move along the shortest path from the current node at the circle centre in accordance with the surface-current direction assigned to this node to another node located inside this circle. Therefore, this path will be the line segment between these two points. The radius of the circle should be designed so that the gradient of the line segment along which the object will move is the best possible approximation of the surface-current direction assigned to the current node. That is, the discretization grid can be represented in the form of a graph whose vertices correspond to the grid nodes and directed edges correspond to line segments which join the corresponding grid nodes; this is possible because the object can move from one vertex to another and get back.

A given area into which the object moves is an infinite set of points. However, the discretization grid of this area is a finite set. We can make a finite number of different movements along line segments between the grid nodes. However, in an unrestricted area we can make an infinite number of these movements. Therefore, the edges of the graph will assign weights to achieve the best approximation of the object's movement in an unrestricted area. The edge weight along which the object will move describes the difference between the gradient of this edge and the direction of the surface current associated with the grid node in which the object is located. The edge weights are nonnegative real numbers. If the weight of some edge is equal to zero, the gradient of this edge (along which the object is moving) will be the same as the surface-current direction associated with the grid node of the outgoing edge.

It can be observed that the vector field of surface currents is not a constant field. Both directions and speeds of these currents associated with the grid nodes can be different. Thus, incoming and outgoing edges with a given vertex can have different weights. As a result, the discretization grid of a given area, together with the data on the currents, can be used to define the weighted directed graph. This graph is a data structure that reflects the surface current's influence on small objects.

The task now is to find a minimum-weight edge that goes out of the vertex where the object is located. This approach allows us to find a method of predicting the route that a small object immersed in water follows together with surface-water masses. This approach allows narrowing down the object's search area. Moreover, it minimizes a single operation time

to search the edge along which the object will move. We do not perform calculations on the entire base of nodes. Therefore, this approach allows us to reduce the computational complexity and memory complexity of algorithms for searching the nodes database.

The graph enables determining the relationships between the grid nodes where data values exist. These nodes can be connected using arrows labeled with directions to model the influence of surface currents on a small object immersed in water. Searching the data in the grid nodes on the basis of graph searching is much more efficient.

The graph theory is widely used in scientific research, including static-network analysis (analysis of a network whose characteristic does not change over time) and dynamic-network analysis (a network analysis which describes time-varying relationships). The static-network analysis provides a basis for many GIS analyses. These networks describe spatial relationships between geographic objects such as road systems, transportation networks, water and land areas, and buildings (e.g., Cichociński, 2012).

The dynamic-network analysis describes time-varying phenomena; an example might be the analysis of traffic stream variability in a number of crossroads (e.g., Alivand, Alesheikh & Malek, 2008). In this case, an object location and the time at which the object has reached its location are important. The characteristic of this network varies over time in either a predictable or an unpredictable way. If properties of the network change over time predictably, then the edge weights are a function of time. This method requires a lot of traffic data from different times and locations of the network. Thus, the weight function must be re-calculated. On the other hand, if properties of the network change over time in an unpredictable way, then the edge weights are re-calculated at each time step. The network is divided into subnetworks and the optimization is done locally in each subnetwork (the search of the shortest path). This method is based on partitioning space-time. One method for doing such partitions is based on the discretization of continuous time to smaller time intervals. At each time interval, the traffic condition is constant. Further, the space is divided according to the time intervals. Therefore, the optimal solution at each time and space interval is provided independently. In order to find the optimal solution for the entire network, this method is integrated with heuristic methods derived from the graph theory. The dynamic-network analysis uses Mobile Geospatial Information Systems (MGIS, as

amended) as a variety of conventional GIS and its main task is to examine a non-geographic object moving in the geographic space.

Hydrodynamic models generate data on sea currents over certain time intervals. Therefore, these data should be updated in the graphical model. Hence, the edge weights of the graph have to be re-calculated whenever up-to-date data on surface currents are provided from the hydrodynamic model to the graphical model.

Essential input data for building a graphical model

We assume that input data that are downloaded to run the model are derived from hydrodynamic models for a given area. These models generate data on currents – specifically their directions and speeds over certain time intervals and in different layers. For instance, in the Polish area, such data can be obtained from the M3D (Kowalewski, 1997) and the HIROMB model (Funquist & Kleine, 2007). These data are computed in nodes of a square-discretization grid of a considered area. Suppose that the data are organized in the form of an array and may be delivered as a file. In the given layer, we get successive data on:

- geographical coordinates of the grid node;
- current direction (in the range from -180° to 180°);
- current speed (in cm/s).

Let us recall that we consider surface currents in the layer up to one meter deep. Therefore, we select a layer in which a chosen hydrodynamic model best reflects the values of these surface currents.

Definition of the graphical model

Let us introduce the following notation:
 $(\lambda_i; \varphi_i)$ – geographical coordinates of the i -th node of the square-discretization grid consisting of the n nodes ($i = 1, 2, \dots, n$);
 λ_i – longitude of the i -th node;
 φ_i – latitude of the i -th node;
 α_i – direction of the surface current at the i -th node with the chosen layer;
 v_i – speed of the surface current at the i -th node with the chosen layer.

In the *weighted directed graph* G : a triple (V, E, f) , where $V \neq \emptyset$, $E \subseteq V^2$, and $f: E \rightarrow R_+ \cup \{0\}$, the set V is called the *vertex set* of the graph G , and $x \in V$ is the *vertex* of the graph G . In turn, the set E is called the *edge set* of the graph G , and $xy \in E$ is

the *directed edge* (briefly the *edge*) of G . The edge xy is called an *outgoing edge* of the vertex x and an *incoming edge* of the vertex y . Moreover, the vertex y is the *neighbour* of the vertex x . The function f is called the *weight function* of the graph G , and $w = f(xy)$ is the *weight* of the edge xy in G .

We can now define the graph $G = (V, E, f)$ as a model of the impact of the surface currents on small objects considered in this paper. The set of vertices of the graph G is defined as the set:

$$V = \{1, 2, 3, \dots, n\} \quad (1)$$

where the vertex i corresponds to the node $(\lambda_i; \varphi_i)$ of the discretization grid of the considered area ($i = 1, 2, \dots, n$).

In order to determine the edge set of the graph, we need to make a certain cartographic transformation of the geographic-coordinate system by changing its centre. The centre of the new geographic-coordinate system is placed in the centre of the considered area (i.e., the translation of the equator and the prime meridian). Both the equator and the prime meridian are moved to the centre of the area. Then the line segment of one geographical degree will be identical along any meridian and along the circumference of the equator.

This system is replaced by the so-called *moved coordinate system* (Pietrek, 2006), which then is expressed in a certain linear system. The reader recalls that $(\lambda_i; \varphi_i)$ means the i -th discretization grid node described in the geographic system. First, we express the coordinates $(\lambda_i; \varphi_i)$ of this node in the Cartesian-coordinate system in the following way (without loss of generality we may put $r = 1$):

$$\begin{aligned} x &= \cos \varphi_i \cdot \cos \lambda_i \\ y &= \cos \varphi_i \cdot \sin \lambda_i \\ z &= \sin \varphi_i \end{aligned} \quad (2)$$

The next step is rotating this Cartesian coordinate system about Oz axis by the angle:

$$\alpha = 0.5 (\min L + \max L) \quad (3)$$

where L is the set of all the longitudes attached to the nodes of the discretization grid. The rotation is done in the following way:

$$O1 = \begin{bmatrix} \cos(-\alpha) & -\sin(-\alpha) & 0 \\ \sin(-\alpha) & \cos(-\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (4)$$

In the 3×1 matrix $O1$, there are Cartesian coordinates of the node (x, y, z) obtained by rotation.

Further, we rotate the obtained system about the Oy axis by the angle:

$$\beta = 0.5 (\min F + \max F) \quad (5)$$

where F is the set of all the latitudes attached to the nodes of the discretization grid. This rotation is done as follows:

$$O2 = \begin{bmatrix} \cos(\beta) & 0 & \sin(\beta) \\ 0 & 1 & 0 \\ -\sin(\beta) & 0 & \cos(\beta) \end{bmatrix} \cdot O1 \quad (6)$$

In the 3×1 matrix $O2$, there are Cartesian coordinates of the node (x, y, z) obtained by two rotations. Let us denote them as follows: x_0, y_0, z_0 . Then, the obtained Cartesian-coordinate system is converted to the geographic system in the following way:

$$\lambda_p = \arctan \frac{y_0}{x_0}; \quad \varphi_p = \arcsin z_0 \quad (7)$$

In this way, we have obtained the coordinates $(\lambda_p; \varphi_p)$ of the discretization grid node in the new, moved coordinate system. In this system, the grid of the area is square. Thus, all the distances between the grid nodes in vertical and horizontal directions are equal.

Next, we should transform this moved coordinate system as:

$$xm_i = \lambda_p \cdot 60 \cdot 1852; \quad ym_i = \varphi_p \cdot 60 \cdot 1852 \quad (8)$$

Then, the coordinates $(xm_i; ym_i)$ of the i -th node of the grid are expressed in meters (1 Mm = 1852 m).

The edge set E of the graph G is in this form:

$$E = \{ij \in V^2: d((x_i; y_i)(x_j; y_j)) \leq r\} \quad (9)$$

where the vertex i of G corresponds to the node $(xm_i; ym_i)$ of the discretization grid in the linear system, the vertex j corresponds to the node $(xm_j; ym_j)$, and $r > 0$. The distance d is the Cartesian distance. Therefore, to obtain all the neighbours of the vertex i , we should find the nodes $(xm_j; ym_j)$, whose maximum distance is r meters from the node $(xm_i; ym_i)$; r is the radius of the circle at the centre in the node $(xm_i; ym_i)$ (Figure 1).

Now we will describe how to obtain the edge weights of the graph G . Consider the vertex i and its neighbour k . Recall that, in the linear system, the node $(xm_i; ym_i)$ corresponds to the vertex i and the node $(xm_k; ym_k)$ corresponds to the vertex k . We calculate certain direction angles of the outgoing edges of the vertex i . Let us consider the following cases:

1. Let $ym_k > ym_i$. Then the direction angle θ_i of the edge ik is defined as follows:

$$\theta_i = \arctan \frac{xm_k - xm_i}{ym_k - ym_i} \text{ (degrees)} \quad (10)$$

2. Let $ym_k = ym_i$ and $xm_k < xm_i$. Then $\theta_i = -90^\circ$.

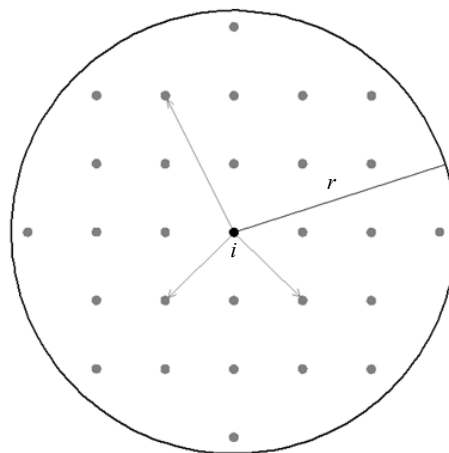


Figure 1. The vertex i , its neighbours, and three possible outgoing edges

3. Let $ym_k = ym_i$ and $xm_k > xm_i$. Then $\theta_i = 90^\circ$.

4. Let $ym_k < ym_i$ and $xm_k < xm_i$. Then

$$\theta_i = \arctan \frac{xm_k - xm_i}{ym_k - ym_i} - 180 \text{ (degrees)} \quad (11)$$

5. Let $ym_k < ym_i$ and $xm_k \geq xm_i$. Then

$$\theta_i = \arctan \frac{xm_k - xm_i}{ym_k - ym_i} + 180 \text{ (degrees)} \quad (12)$$

The direction angle θ_i of the outgoing edge of the vertex i is the angle between this edge and the north direction.

Recall that the direction of the surface current generated by the hydrodynamic model at the i -th node of the discretization grid is denoted by α_i . The i -th node of the grid corresponds to the vertex i of the graph G . For the edge ik of G , we set $b = |\theta_i - \alpha_i|$. The weight function $f: E \rightarrow R_+ \cup \{0\}$ is defined as follows:

$$f(ik) = \begin{cases} b, & b \leq 180 \\ 360 - b, & b > 180 \end{cases} \quad (13)$$

The number $w = f(ik)$ is called the weight of the edge ik .

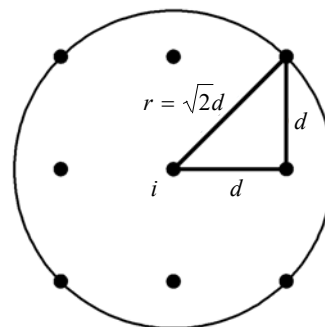


Figure 2. The vertex i and its neighbours in the first iteration

We will now describe how to select the radius r of the circle in which all the neighbours of the given vertex will be located. Let us assume that for the vertex i we determine all its neighbours. Recall that in the linear system, the grid node $(xm_i; ym_i)$ corresponds to the vertex i of the graph. In the first step, the radius of the circle is selected as follows:

$$r = \sqrt{2} \cdot d \tag{14}$$

where d is the discretization-grid step in the linear system (Figure 2). In this case, the vertex i has eight neighbours. The considered object will move from the vertex i along its outgoing edge with the minimum weight. Therefore, we would like to obtain the number b , associated to that edge, which is as small as possible. The maximum possible value b for such an edge is 22.5° . We assume the movement-direction accuracy δ , which is the maximum possible angular difference between the direction of this outgoing edge and surface-current direction assigned to the vertex i . Furthermore, we also assume that the data assigned by the hydrodynamic model are updated every Δt time units. If the weight of this outgoing edge is not greater than δ and the time needed to move along this edge is less than $0.1 \cdot \Delta t$, then $r = \sqrt{2} \cdot d$.

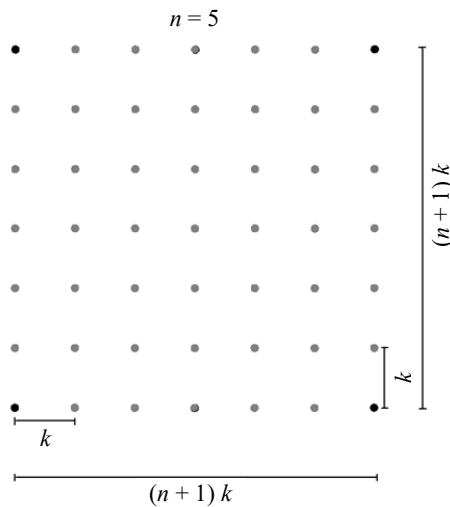


Figure 3. A part of the grid after interpolation

In another case, we should make an interpolation on the discretization grid. We then generate n additional grid nodes in the vertical and horizontal direction between each two old-grid nodes. In the new nodes, we assign surface-current speeds and directions. The bilinear interpolation is proposed to determine the surface currents at these additional nodes (Pyrczla, 2008). We first select a value for n (e.g., $n = 5$) in order to not increase computing

power too much, but to improve the direction of the predicted object's movement. If this direction is still incorrect, we should repeat the interpolation. For what is intended, at the least movement direction accuracy δ of the object at the given node, we establish $r = 2^{1/2} \cdot (n + 1) \cdot k \cdot a$, where k is the discretization step of the new grid (Figure 3) and a ($0 < a \leq 1$) is a scale of decreasing the radius of the circle (Figure 4). Initially, we can select $a = 0.5$. If the time of the moving object along the chosen edge is too long (longer than Δt), we can establish the scale a as, e.g., $a = 0.4$, $a = 0.3$, $a = 0.2$, $a = 0.1$.

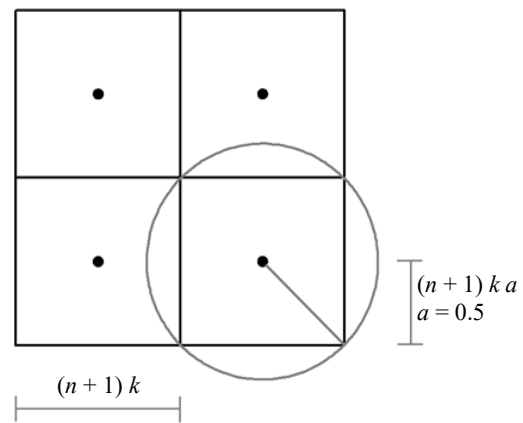


Figure 4. Selecting the scale a of decreasing the radius of the circle in the grid before the interpolation

Functional description of the graphical model

Suppose that the object is located at the i -th node of the discretization grid. Recall that the i -th node of the grid corresponds to the vertex i of the graph G . The movement of this object defined by the model will take place as follows:

- We select the outgoing edge of the vertex i with the minimum weight. The object will move along this edge.
- We determine the time required to move from the vertex i to another vertex along this edge. This time is determined on the basis of the surface-current speed assigned to the i -th node by the hydrodynamic model. Suppose that the object will move at a constant speed along the selected edge. Therefore, the time required to move along this edge equals s/v , where s is the length of the route along the chosen edge and v is the surface current speed assigned to the i -th node.
- Steps 1 and 2 are repeated and the times required to move along the chosen edges of the graph are summed. If the sum of the time lengths is equal

to Δt , then the graphical model updates the data on the surface currents and re-calculates the edge weights of the graph, and returns to step 1.

- The model terminates when it reaches the vertex corresponding to the grid node located on land or when it exceeds the simulation time of the object's movement.

Conclusions

The graphical model has been designed to provide a tool to reflect the influence of surface currents on small objects immersed in water, e.g. in coastal areas or harbours. The graphical model allows us to predict the route of small objects immersed in water that move together with surface water masses, e.g. a person in water who does not drift in the wind, but only with currents. As a consequence, this approach can narrow down the search area of the object. In addition, this solution may be used to determine the characteristics of water exchange based on the environmental-risk-management model methodology. The model is based on the directions and speeds of the surface currents generated by a hydrodynamic model. In the given time steps, the proposed model updates surface-current data. The graphical model

is characterized by its simplicity, which ensures that results are obtained very quickly. Furthermore, this approach can increase the productivity of grid-node searches.

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Methods for building a knowledge base for automatic communication in shipping

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Abstract

One of the most significant phases for automation of communication processes in shipping is building a knowledge base for inference processes. Communication processes include: exchange of information, perception of communication and interaction between navigators. Computing with words has been used to represent inference processes covering imprecise concepts that are characteristic of natural languages. Elements of classical predicate calculus were adopted as a basic form of writing inference rules. Methods for constructing a knowledge base were chosen. The knowledge base architecture was proposed. This article also presents examples of inference rules in a knowledge base for automatic communication in shipping.

Introduction

The process of ship conduct requires constant information exchange and processing of navigational information. Human error is one of the main causes of shipping accidents. They can result from a lack of the information necessary to make decisions, or their misinterpretation, but also from an overload of information, hindering the processing and selection of information relevant to the decision-making process. Navigators, to assess the situation and make decisions, use shipboard devices and systems, and means of verbal communication. Verbal communication comprises of the exchange of information, including the acquisition of additional information and, if appropriate, negotiations.

Problems with correct verbal communication are mostly associated with the failure to communicate, misunderstanding messages, a wrong choice of message or misinterpretation of the information exchanged. These errors can be due to navigators' mental and physical state, particularly with regard to stress and fatigue.

One of the proposed solutions is the automation of communication processes in shipping, incorporating such aspects as selective acquisition of information, including other navigators' intentions and their interpretation, and taking into account interactions between the navigators, their negotiations in particular. The automation of communication processes requires a knowledge base to be developed for inference processes to take place. Such a knowledge base has to allow for the complexity of communication processes, including negotiations, and the specifics of marine navigation.

The construction of the knowledge base

When creating knowledge bases and generating rules, it is necessary to define the properties these bases and rules should have. A knowledge base may represent a particular scope of knowledge in a variety of ways. For automatic communication in shipping we have chosen a rule-based knowledge base, i.e. the rule base. The rules have the form "If ... then ..." and take into account assumptions of fuzzy logic

to include imprecise terms of natural language. For the building of knowledge bases and rule bases, the following properties are generally pointed out (Piegat, 1999):

- dependence of the number of rules on the number of inputs and fuzzy sets;
- completeness;
- compatibility (consistency);
- continuity;
- redundancy.

The rule base in question does not have to meet all of these requirements.

In the case of a knowledge base containing rules of fuzzy logic, one essential feature is the exponential dependence of the number of rules on the number of inputs and the number of fuzzy sets in the model. This entails a rapid increase of model complexity that, on the one hand, can raise the accuracy of the mapping of the real system, but on the other hand, can require more information to determine the parameters of the membership function. The base under construction quickly becomes complex, which can lead to difficulties in maintaining its other vital features.

The rule base is defined as complete if the base can assign a certain state of the output to every state of the input. The database is not complete if there are such input states to which this base cannot assign any output state. A model with a complete database of rules more accurately represents the operation of a real system, but in the early stages of rule generation and testing the base is incomplete. Due to the dynamics of verbal communication problems and the diversity of navigational situations, the knowledge base under construction is referred to as an incomplete base, which in specific cases has a capability of generating new rules that are then added to the base.

The rule base is consistent if it does not contain conflicting rules, i.e. rules based on the same preconditions but with different conclusions. This may be due to rule generation errors or the ambiguity of the real system itself.

The rule base in the fuzzy inference system is continuous if it has no neighbouring rules: $R_j R_k$ with respective conclusions, h_j, h_k , whose product is empty, i.e. $h_j \cap h_k = \emptyset$. The continuity of the rule base is recommended but not necessary. Discontinuity means rapid changes in the values of conclusions.

The redundancy of a database occurs when it contains two or more identical rules that were created, for example, at various stages of the base construction. The knowledge base should not have redundant rules.

Stages of knowledge base construction

Building a knowledge base takes place in the steps shown in Figure 1 (Kent, 2000)

Identification involves determining the characteristics of the problem being solved. The problem itself and the scope it relates to are defined precisely.

Representation means working out a manner of knowledge representation. Once the problem is analysed and understood, we can determine the information and data needed to solve the problem. The gathering of necessary data starts at this stage.

Formalisation is the stage in which structures that organise the knowledge are designed, that is key concepts, rules and relationships are translated into formal language. The syntax and semantics of the language are developed, then all the basic concepts and relations necessary to solve the given problem are established.

Implementation means the formulation of the rules or framework comprising the knowledge. At this stage, the formalised knowledge of the previous stage is combined and reorganised so as to make it compatible with the characteristics of the information flow of a given problem. The resulting set of rules or frames and the associated control structure create a prototype program.

Testing is the last stage of building a knowledge base. It involves checking the system rules or frames. The rules and relations are tested for generation of correct responses.

This article will cover the elements of the first three stages.

The processes of inference

Automatic communication in shipping encompasses three basic processes:

- identification of a navigational situation;
- classification of the navigational situation (navigational situation recognition);
- communication processes.

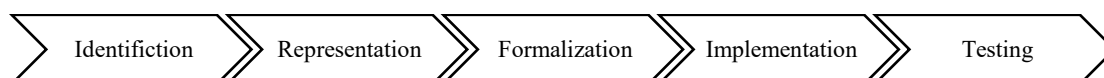


Figure 1. Stages of knowledge base construction

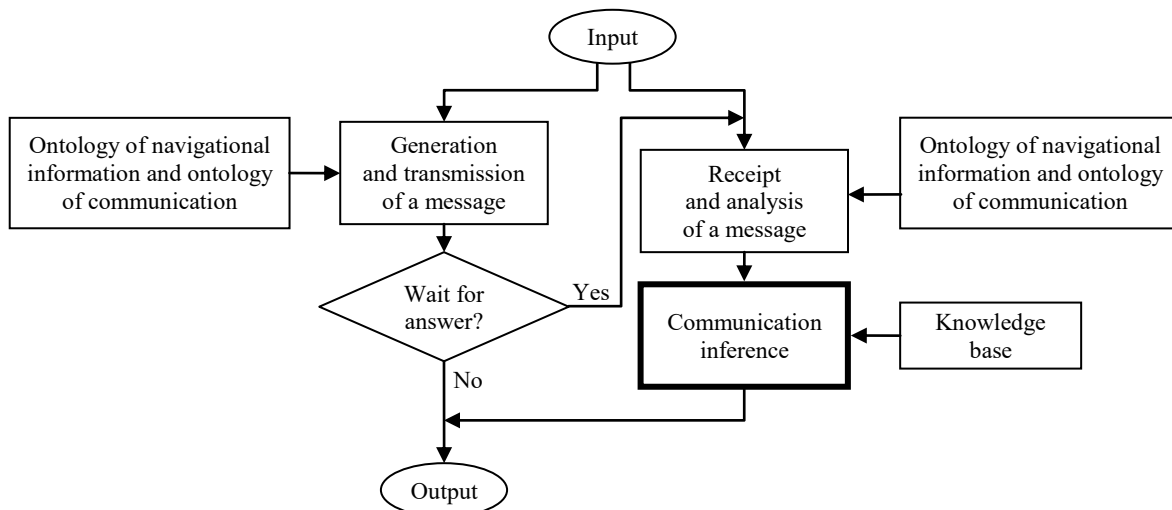


Figure 2. Schematic communication process (Pietrzykowski et al., 2015)

The first process aims at identifying potential risks arising from an encounter. Based on the analysis of the current situation, including parameters CPA and TCPA, it is identified either as safe or potentially dangerous. This step of the system operation is referred to as the preliminary inference.

The classification of a navigational situation comes next, based on the Collision Regulations. Decisions are made concerning which ship has the right of way, the need for manoeuvres to be performed by the navigators conducting their vessels, and the possible need for establishing verbal communication. The process of inference at this stage is inference proper.

Finally, communication processes including reception and analysis of information, and inference on that basis, as well as generating and sending feedback to the target vessel’s navigator or automatic communication system, are shown in Figure 2.

Let us consider two cases:

- the system identifies a situation that requires establishing communication;
- the system is called by another ship (by receiving a message).

After the message is interpreted using the ontologies of navigational information and communication, the data is transmitted to the Communication Inference block. The input data to this block are messages received from another ship or a coast station in text form (natural language) as well as data from shipboard systems. If the input data is crisp, the performed inference is of classical type, using the knowledge base. If the input data includes imprecise terms, the system makes use of inference using fuzzy logic and methods of computing with words (Figure 3).

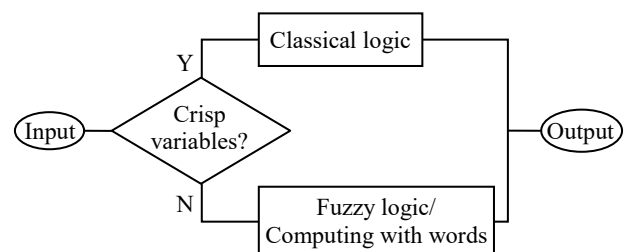


Figure 3. Diagram of inference processes in communication (Wójcik, Hatlas & Pietrzykowski, 2016)

The system works on the principles of fuzzy inference systems with a properly constructed knowledge base. Fuzzy systems can be divided into four basic elements, shown in Figure 4.

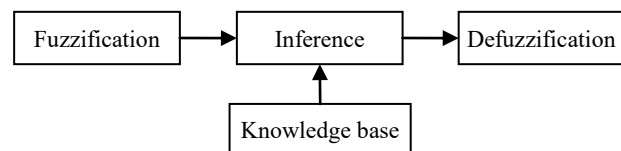


Figure 4. Diagram of fuzzy inference processes

Input values of linguistic variables are expressed by fuzzy sets in the fuzzification block. The input values are fuzzified by assigning a membership function assuming a value from the interval $[0, 1]$ to a variable. In the event of a crisp value occurring at the input, the fuzzification of a singleton type, the membership function takes only the values 0 or 1.

In the inference block, those rules from the knowledge base are executed whose preconditions are met by the data of the previous block. The system calculates a fuzzy set resulting from the operation of the model used, e.g. Mamdani or Takagi–Sugeno model.

The defuzzification block is responsible for mapping a fuzzy set that came out of the inference block onto a value that will be an output of the fuzzy system.

The knowledge base is a collection of data relating to a specific area with the logic rules allowing for inference.

The knowledge base created for automatic communication in shipping is expected to allow inference on the basis of crisp and fuzzy input data, with possible use of computing with words. To this end, we propose to build a relational knowledge base. The rules in this base principally take the following form (Pietrzykowski et al., 2011):

rule: <preconditions> \rightarrow <conclusions>

where: <preconditions> (often called premises) indicate when a given rule may be applied, and <conclusions> denote the effect of rule application, which may be a logical value, a decision or action.

The rules often contain a few preconditions, linked by logical connectives, leading to a single conclusion, and are written as follows:

r : IF p_1 AND p_2 AND p_3 ... AND p_n THEN h

where: r means a rule, $p_1, p_2, p_3, \dots, p_n$ – preconditions, and h denotes a conclusion.

Preconditions may be built using propositional logic, attributive logic or classical predicate calculus, i.e. first-order logic.

Methods of building the knowledge base

When using propositional logic, it is assumed that each sentence can be assigned one of two logical values: true or false. This causes limitations in knowledge representation. The syntax features propositional variables (sentences), sentence-forming functors (i.e. propositional connectives) and auxiliary symbols (e.g. parentheses). Inference systems may, for example, take the form of decision tables, decision lists, decision rules with control rules or a decision tree (Ligęza, 2006).

In case of attribute logic using attributes and values, the attribute is used to write down some properties of objects and the system to which they are applied. A set of characteristic attributes is chosen, with certain values assigned to them. This method is most often used to define facts concerning a system, specifications and properties of programs and their components.

The classical predicate calculus is the most popular way of recording the statements used to express

the knowledge described in natural language. It allows the use of variables, conditions and quantifiers, which make it possible to formalize complex knowledge. This method was chosen as the basis for writing down the rules in the system of automatic communication and will be described in detail in the next section.

Depending on the selected method of statement notation, the activation of rules is dependent on the fulfilment of conditions and the choice of a rule by the inference machine. The rules are selected and checked by the inference machine using different predefined algorithms. These may be methods of checking the rules for selected properties, in a serial or parallel manner. Individual rules are then checked for the fulfilment of preconditions.

The classical predicate calculus

For this proposed system of automatic communication in shipping, classical predicate calculus has been adopted as the primary method of rule notation. This choice is dictated by the nature of ambiguous input, which may take the form of imprecise terms of natural language.

The term predicate means a property or relationship of certain objects which are its arguments. N is the argument predicate over a class of individuals; X denotes the mapping

$$P: X^n \rightarrow \{F, T\}$$

that to every n -element string of individuals assigns a Boolean value, false – F or true – T. The basic statement in the predicate calculus assumes the form $P(x_1, x_2, x_3, \dots, x_n)$ and means that the relation P is maintained for objects $x_1, x_2, x_3, \dots, x_n$. The individual variable x is bound in an expression if x is a variable of the quantifier $\forall x$ (for every x), or $\exists x$ (there exists x), otherwise the variable x in this expression is free. The expression containing no free variables is called a closed form.

A propositional expression is interpreted as a closed form. If a predicate expression contains a free variable, then it is interpreted as a relation in a certain class of individuals. The expression of predicate calculus is defined as true in a given interpretation if any substitution of class individuals in place of variables leads to a true sentence. Formulas of classical predicate calculus are constructed in the same manner as in propositional calculus, but with the addition of variables and quantifiers.

The knowledge base under construction will contain inference rules and metarules (rules instructing

how to use other rules). Let us consider an encounter of two vessels A – Alpha and B – Beta, proceeding on reciprocal courses (Pietrzykowski et al., 2011), for which we will write down an example form of an inference rule (Figure 5).

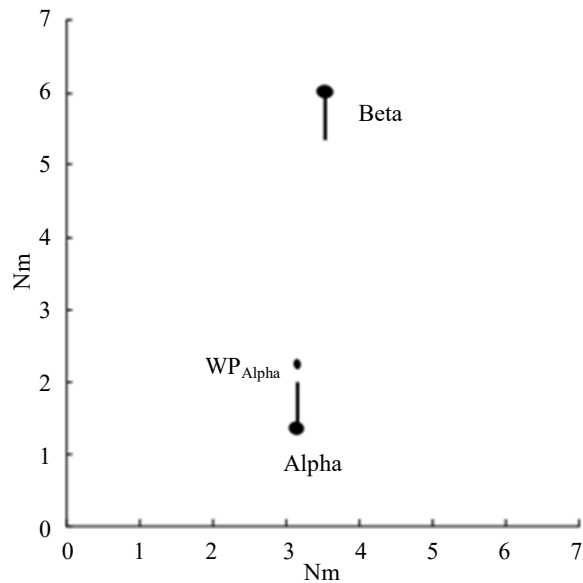


Figure 5. An example navigational situation

According to the regulations in force, the ships should pass each other port-to-port. For the presented situation, part of verbal communication of the ships' navigators may go like this:

A: Our CPA is 0.2 Nm.

A: I intend to alter my course to starboard soon and cross ahead of you at a safe distance.

B: Ok, cross ahead of me at a distance farther than 1.2 Nm.

Inference processes are considered from the viewpoint of the system on the ship Alpha.

An example notation of the rule for the above dialog has this form:

$$\begin{aligned} &\forall A, B \in \text{ships} \\ &[\text{relative bearing}(A, 5) \wedge \text{aspect}(B, 5) \\ &\wedge \text{CPA}(A, B) \wedge \text{wp}(A)] \\ &\rightarrow [\text{manoeuvre}(A, \text{passing}) \\ &\wedge \text{manoeuvre}(B, \text{standing on}) \\ &\wedge \text{inf o preparation}] \end{aligned}$$

where:

relative bearing (A, 5) – angle $A \leq 5^\circ$;

aspect (B, 5) – aspect $B \leq 5^\circ$;

CPA(A, B) – $\text{CPA}(A, B) \leq \text{CPA}_{\text{Limit}}$;

wp(A) – information on next way point.

This notation represents a formal record of rules of inference and metarules that will be generated in further research. The notation takes into account the

accepted methods of knowledge representation in the inference system for automatic communication.

Conclusions

The verbal communication discussed herein involves the exchange of information, including acquisition of additional information and, where appropriate, negotiations. Problems of normal vocal communication are most often associated with failure to establish radio communication, misunderstanding of messages, improper choice of message (wording) or incorrect interpretation of information being exchanged.

The proposed system of automatic communication can help reduce these errors. The system is built on a rule base, a specific type of knowledge base. The rules are written in line with classical predicate calculus using fuzzy logic for imprecise terms of natural language.

The article characterises stages of building a knowledge base and identifies the properties of the rule base required for inference processes. Selected elements of the knowledge base are presented along with an example of formal notation of inference rules. This kind of notation allows us to develop inference rules and the governing rules, often referred to as metarules. Currently, the test environment is being prepared to verify the created rules.

Acknowledgments

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Technology profile

Utilising water wave energy – technology profile

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Key words: wave energy, energy conversion, shore protection, mechanical motor, active damper

Abstract

The use of wave energy was studied at the Maritime University of Szczecin. The two main subjects were wave-energy conversion and using wave energy to protect the seashore against the hazardous effects of extreme waves. A construction of new technologies were outlined. Future research and intended cooperation were presented.

Wave energy conversion

The growing demand for energy in developed countries and the necessity to ensure energy security for those countries make the search for new, effective methods to produce energy from renewable sources real. One of these sources is seas and oceans. Among currently-developed generation technologies for deriving energy from seas and oceans, we should distinguish systems that produce energy from (Chybowski & Kuźniewski, 2015a):

- rippling water;
- sea currents;
- sea tides;
- salinity gradient;
- temperature gradient.

Energy converters can be classified into three basic groups (Wallace, 2014), depending on their method of functioning:

- point absorbers, characterised by small size relative to the incident wavelength;
- attenuators, in which the production axis of the device is perpendicular to the wave front and energy is intercepted by device components moving due to the passing wave;
- terminators, in which the principal axis of the device is parallel to the wave front and energy is acquired by interception of a wave.

Nowadays, there are constructions utilising energy-conversion systems based on the following systems:

- power hydraulics;
- pneumatics;
- electromagnetics;
- complex mechanical gears.

Wave-energy conversion is very complicated and has difficulties caused by a complex wave-propagation process and a continuous, cyclical change in wave direction in every vertical cross-section parallel to the direction of wave propagation (Chybowski & Kuźniewski 2015a).

The study results are two simple constructions of wave energy converters, which have a patent granted (Kuźniewski, 2013) and patent pending (Chybowski & Kuźniewski, 2015b). The subject matter of the invention is the method of transforming wave energy into electricity (Figure 1).

It requires installation of a generating set, composed of a generator and an engine with a gear box at a distance from the shore, beneath the surface of sea rippled by waves, on a platform moored to the sea floor (Chybowski & Kuźniewski, 2015a). Energy for the generator propulsion is acquired directly from the oscillating water by means of a driving unit installed on the engine shaft (Figure 2).

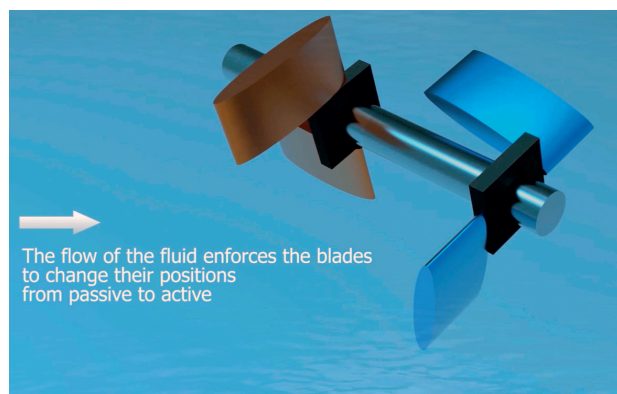


Figure 1. Principle of energy-converter work (MUS, 2015)

The construction of the device vertically with the drive shaft line is presented in Figure 3. Working in this layout required a change in the construction of the blades, changing the kinematics of a blade by the use of elements (6) and changing the geometry of the drive transmission system. The device consists of the motor (1) that drives the power receiver (7), namely the direct drive electric generator through the clutch (8) or through the mechanical gear.

The motor is comprised of a drive shaft (4) on which are two pairs of blades (2 and 2'). The purpose of the blades (2, 2') is to intercept the thrust of the passing fluid and transfer it to the drive shaft (4), which transmits the energy to the receiver. Blades (2, 2'), which work in pairs, ensure a constant direction of shaft rotation regardless of the current direction, sense, and magnitude of the driving fluid thrust, all of which vary in time. Blades (2, 2') are connected to the drive shaft (4) via bearings (3). The passing fluid pushes against one of the blades (2), which is in the active state, and at the same time the other cooperating blades (2'') switch to the passive position. The thrust is transmitted from the blades (2) to the drive shaft, which rotates and drives the power receiver.

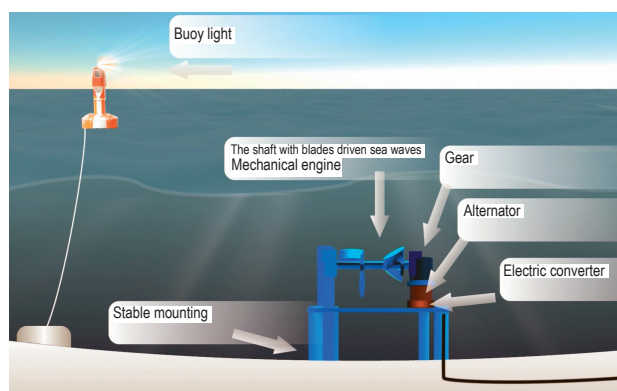


Figure 2. Main components of the underwater wave-energy converting system (MUS, 2015)

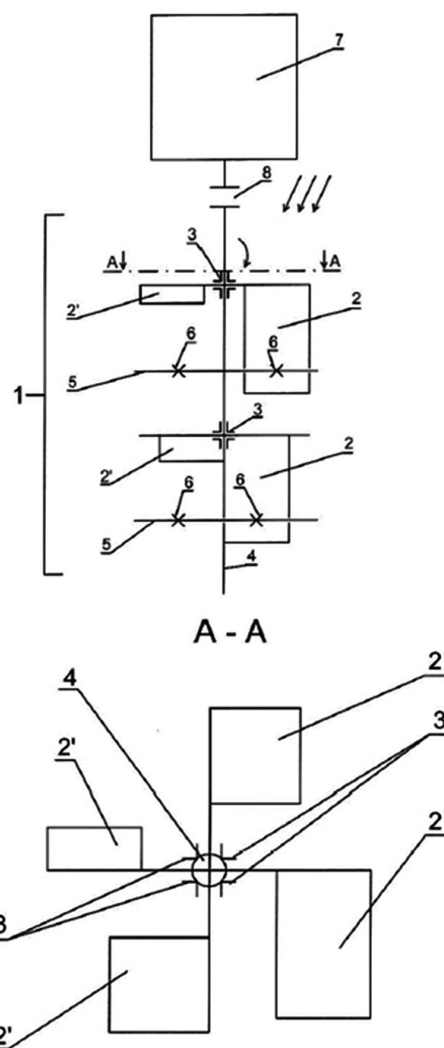


Figure 3. Energy converter construction (Chybowski & Kuźniewski, 2015)

Innovative aspect of the invention

The proposed solution, compared to currently-operated power stations generating electric energy from sea waves (CMTT, 2014):

- has a much simpler construction and is cheaper;
- offers a variety of installation methods (flexible system, direct or indirect propulsion, etc.);
- looks more attractive than floating systems currently in use.

Shore protection against sea waves

As a result of studies at the Maritime University of Szczecin, there is a concept of suppressing sea power with its own energy (Kuźniewski, 2007). An active technology of shore protection has been proposed that is different from passive methods used so far. This active technology uses wave damping before it reaches the shore. In other words, it is

a breakwater installed and submerged in the distance between several and several-hundred meters off of the coast (Chybowski & Kuźniewski, 2015a).

The submarine breakwater consists of vertically-installed pipes closed from both sides and mutually joined by rigid clamps (Figure 4). The breakwater weight is less than the displaced water quantity, as it stays submerged and is stabilised by ropes moored to the sea floor. A modular breakwater construction is based on the principle of an equilateral triangle where the length of the triangle side determines the distance between the pipes, which varies from one to several meters (Chybowski & Kuźniewski, 2015a).

The essence of how the system works is depicted in Figure 5 where an assembly that damps the sea waves' energy is shown in both the horizontal and vertical view. Vertical elements (8) are interconnected by means of clamps (7) and rigid truss sections (9). The damping assembly, the weight of which is considerably smaller than the buoyancy force, is kept under the surface of water by means of tie rods (6) attached to anchor elements (5) resting on the seabed (4).

Figure 5 depicts the assembly damping the energy of sea waves in a horizontal view with its front located in the rippling layer of water. Also, it shows a unit for seashore protection consisting of three damping assemblies located in rows in the water at a sufficient distance from the shoreline (11), behind the wave transformation line. The vertical component (8) is a tube, closed at both ends, being a natural floater with a specific buoyancy force.

On each vertical element, in their top and bottom part, there are clamps (7) which are attached to the cut-off tops of rigid spacers (9), namely truss sections. Spacers (9) join the individual vertical elements (8) in their top and bottom part to form two rigid trusses. The essence of the method proposed in the patent application for damping the water waves is that the damping assembly is placed in the layer of rippling water. The said assembly consists of a large number of vertically spaced pipes, closed at both ends and interconnected by means of rigid brackets.

Wave-induced forces compensate owing to their interaction with breakwater components whose distance to each other is equal to half of the wave length in the direction of wave propagation. Simultaneously, with the forces' compensation, wave energy dissipates and wave height decreases. The breakwater effectiveness increases when additional components with improved damping properties are installed (Chybowski & Kuźniewski, 2015a).

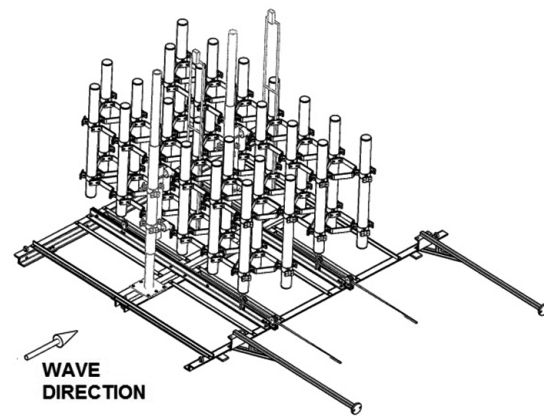


Figure 4. View of an active damper (NCRD, 2010)

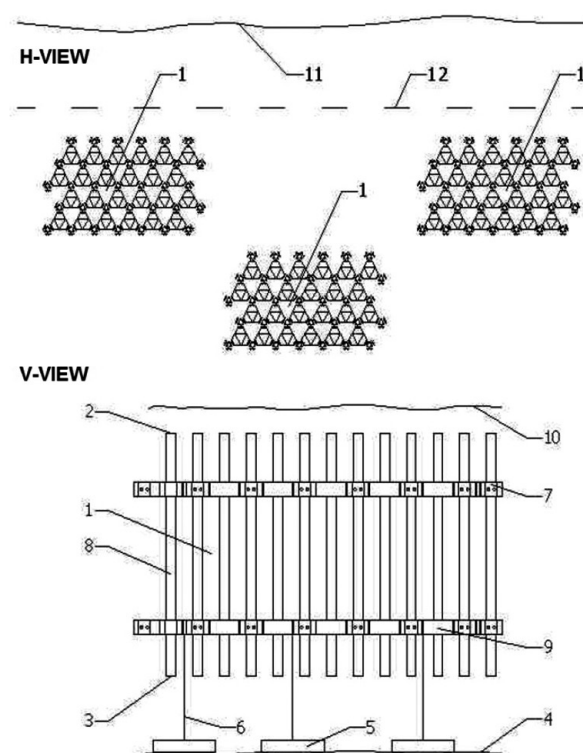


Figure 5. Active damper construction (NCRD, 2010)

The design work was supported with state-of-the-art computer simulation software. Experimental research (Figure 6), which was carried out in the model pool of the Ship Hydromechanics Division, Ship Design and Research Centre SA in Gdańsk, has confirmed that the damping device functions as stated in the theses of the developed concept.

The research findings showed that the damping of the water wave exceeded 70% and the level of compensation of the horizontal forces was high. The positive results of experimental research, after their verification and further studies in more complex sea conditions, will create the possibility of practical application of a new method of seashore protection against storm surges.



Figure 6. Testing the submarine breakwater prototype in the towing tank of the Ship Hydromechanics Division, Ship Design and Research Centre SA, Gdańsk (NCRD, 2010)

Innovative aspect of the invention

The proposed solution, compared to existing ferroconcrete breakwaters, mainly in the form of star-shaped blocks (CMTT, 2014):

- is much cheaper;
- looks more attractive (important for seaside resorts);
- is easier to install (a wide range of system parameters modifications).

The proposed active technology of the coastline protection against erosion resulting from storm waves is environmentally friendly, does not affect the nature of the coast, reduces its running costs, and its construction still promotes the attractiveness of the coastline for recreational and tourist purposes.

Intended cooperation

Presented inventions need to be fully checked in their field conditions. In addition, we would like to test in real conditions the newly-developed concept from the Maritime University of Szczecin that uses composite metal materials for construction of the elements of presented solutions (Gawdzińska, Chybowski & Przetakiewicz, 2015; Gawdzińska et al., 2016).

In the event that you are interested in getting a licence or performing research and engaging in industrial co-operation, please contact MUS Innovation Centre LLC (<http://innoam.pl/>).

Acknowledgments

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Maritime University of Szczecin

The Maritime University of Szczecin (MUS) continues the tradition of marine-related education at Szczecin's maritime schools that was established in 1947. Since then, it has developed dynamically and maintained the highest standards in all areas of research and education.

MUS is recognized by the maritime industry as an important research centre developing marine engineering, navigation, transportation engineering and many other fields. MUS provide research services by **Green Energy – laboratory of wind power plants, Marine Fuel and Lubricating Oils Laboratory, Maritime Risk Analysis Center and Marine Power Plants Laboratory.**

Experts at the University develop innovative concepts like the LNG terminal in Świnoujście. The **European LNG Training Centre** (at MUS) provides the necessary training and awards the required qualifications for operating the terminal LNG equipment and LNG tankers.

The Baltic Fishing Training Centre in Kołobrzeg is a new MUS unit, established in June 2013. There are plans to set up a European Maritime Education Centre in co-operation with other universities of the Baltic states. This project involves two MUS training units, the Marine Traffic Engineering Centre and the Marine Rescue Centre. These units, equipped with several state-of-the-art simulators, will be run a broad training courses for Polish and foreign seafarers of all ranks.

The Marine Rescue Training Centre, one of the largest and best equipped centers of its type in Poland, offers training courses covering areas such as safety, life rescue, health security and environment protection. Participants are trained to respond in extreme emergency situations.

The Training Centre for Marine Officers runs training qualifications and specialized courses for merchant and fishing fleets officers.

The education of mariners calls for thorough onboard seamanship training. Part of this training takes place aboard the modern research-training vessel **Navigator XXI**.

MUS graduates, with an excellent academic background of theoretical knowledge and practical skills, become specialists recognized in Europe and internationally. At present, students can choose a program at one of our three faculties, all conferring bachelor, master and doctoral degrees in Polish, or in English (selected programs).

Faculty of Engineering and Transport Economics

The Faculty educates personnel highly qualified in production management and engineering, port and fleet operations, transport logistics and systems. The programs are specially designed suit the needs of future prospective employers: forwarding, transport and logistics firms, operators in seaports and inland ports.

The following fields of study are available:

- Management and production engineering
- Transport
- Logistics

Faculty of Marine Engineering

The Faculty of Marine Engineering offers courses in two major fields:

- Mechanical engineering
- Mechatronics

These program's focus on theoretical and practical issues relating to the maritime industry, maintenance and operation of marine power plants, electric power systems, diagnostics of shipboard and industrial machines, and wind farms.

Faculty of Navigation

The Faculty teaching staff, many holding scientific degrees or professional titles combined with substantial experience and expertise of Master Mariner or Chief Officer, ensure the highest standards of academic education in accordance with the requirements of the STCW Convention. The faculty researchers focus on navigation safety, marine traffic engineering, navigation automation and the optimization of ocean routes, geomatics and hydrography.

The following fields of study are available:

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- Transport
- Geodesy and cartography
- Computer science



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We got a ministry grant for our quarterly development

We hereby inform, that the quarterly *Zeszyty Naukowe Akademii Morskiej w Szczecinie*, *Scientific Journals of the Maritime University of Szczecin* following Decision No. 790/P-DUN/2016 of 17 June 2016 received funding for the years from 2016 to 2017 from the Ministry of Science and Higher Education of Poland for the activities of promoting science.

The project includes the following tasks:

1. Digitalization of 72 volumes of the Scientific Journals published between 1973–2003 and their distribution on the Open Access basis (task type: digitalization of publications and scientific monographs to provide and maintain access to them through the Internet).
2. Translations and proofreading by a native speaker (task type: creating the English version of publications).
3. Publications of foreign, distinguished scientists and their participation in the scientific board (task type: participation of foreign, distinguished scientists in the scientific board of the journal).
4. Development of web-based editorial module for exchange of articles in the editor – author – reviewer system (task type: participation of foreign, distinguished scientists in the scientific board of the journal).

The tasks will be carried out in the period from 1 January 2016 to 31 December 2017.

