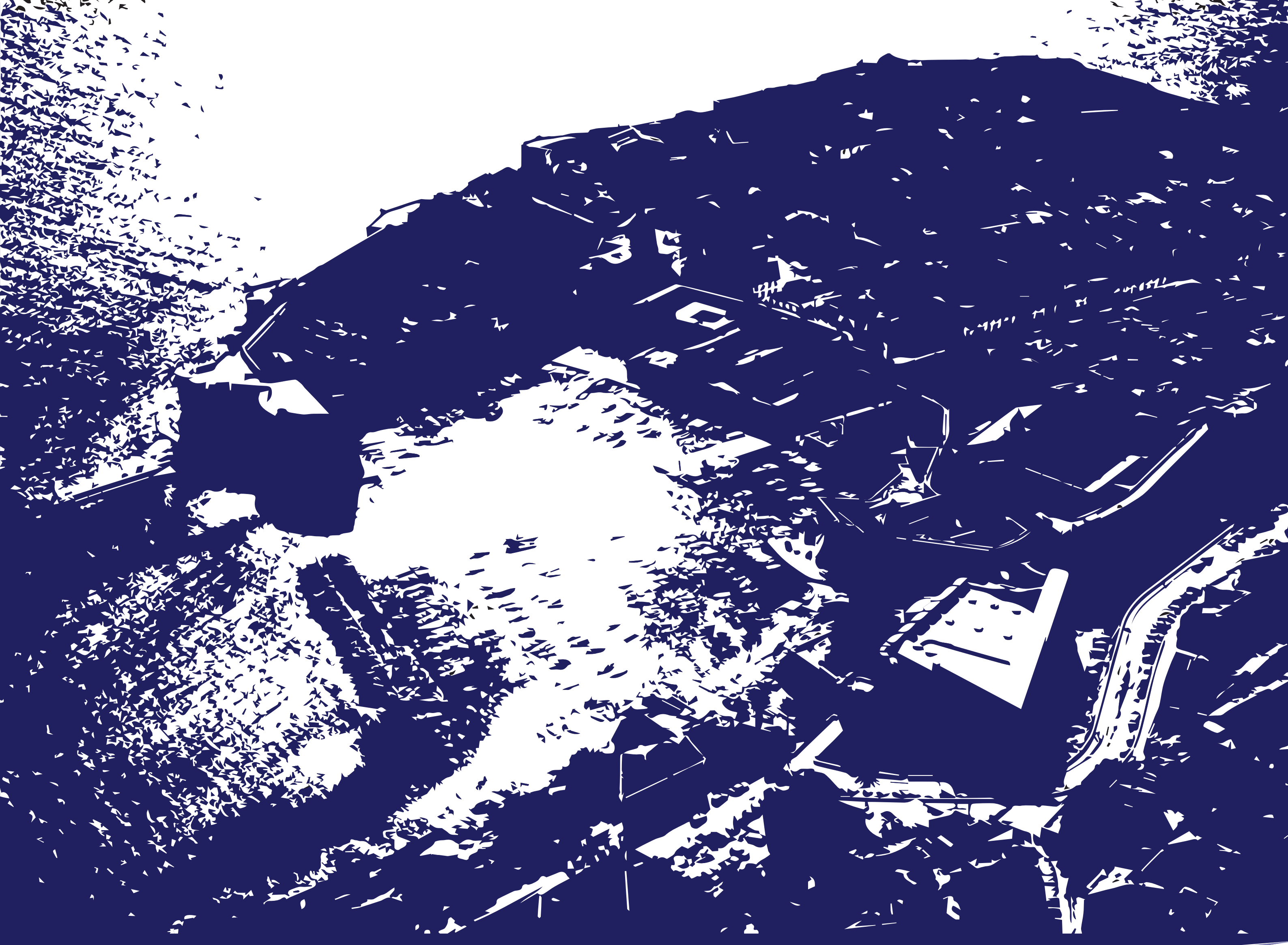


NAŠE MORE 2021

2nd International Conference of Maritime Science & Technology

Dubrovnik, 17 - 18th September 2021

University of Dubrovnik
Maritime Department

2nd International Conference of Maritime Science & Technology

NAŠE MORE 2021

CONFERENCE PROCEEDINGS

Maritime Department
University of Dubrovnik

Dubrovnik, Croatia
17 – 18 September 2021

PUBLISHER
University of Dubrovnik, Maritime Department

EDITOR IN CHIEF
Darijo Mišković, PhD

CO-EDITOR
Nermin Hasanspahić, PhD

INTERNATIONAL SCIENTIFIC COMMITTEE

TECHNICAL EDITOR
Davorka Turčinović, mag. oec.

GRAPHIC DESIGN & EDITING
Katarina Banović, mag. oec
Daniela Tomašević, univ. spec. oec.

LANGUAGE EDITOR
Martina Hrnić, univ. spec. philol.

CLASSIFICATION OF ARTICLES
Ana Pujo, Sc. librarian

The papers are peer-reviewed by international experts.

ISBN 978-953-7153-60-1

CIP record is available in the computer catalogue under number 581131080.

CONTENT

EUROPEAN UNION POLICIES AND FUNDING FOR SMART PORT MODEL IMPLEMENTATION

Adrijana Agatić
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: agatic@pfri.hr

Tanja Poletan Jugović
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: poletan@pfri.hr

Edvard Tijan
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: etijan@pfri.hr

Ines Kolanović
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: ines@pfri.hr

UDK 656.615:004
327:336.69(4-6EU)

Summary

Port activities are of great importance in the European Union. In recent times, digitalization of the port business is increasingly present. As technology develops, and the global supply chain becomes increasingly digital, ports are adapting their activities and business models by implementing digital technologies. Thus, ports are becoming "digital nodes". The Smart Port model is considered to be the most prominent for the future development of the ports. The European Union institutions and organizations strive to provide the administrative and funding support, to keep up the pace with changes in the port business and implementation of the Smart Port model. In this paper, the role of relevant European Union institutions and organizations in Smart Port implementation is researched. The authors present a review of the relevant EU policies and funding for the implementation of the Smart Port initiatives/projects. Furthermore, the authors present examples of the Smart Port projects.

Keywords: Smart Port model, European Union policies, European Union funding

1. INTRODUCTION

Port business has significant role in the European Union (EU) economy. Ports provide service to many other industrial sectors and are important links in inter-modal logistic chains. Ports play an important role in facilitating the European Union's external trade (share of 90%) and internal trade (share of 40%) [10]. Furthermore, ports are also important job generators in the European Union. At the European Union level, employment effects of port activities (direct, indirect, induced and related activities) contribute significantly to the GDP and economic growth. In the perspective of the economic recovery, good port services are of key importance for the competitiveness of European Union export companies in the world markets [10].

The European Union ports, as ports in general, are influenced by several processes. The increase in maritime transport multiplies ports activities. Furthermore, maritime transport is dominant with a share of 80%, compared to other modes of transport [35]. Sustainable development requires ports to carry out activities with rational use of resources in order to reduce or prevent damage to the environment. Ports are significantly influenced by digitalization - an innovative approach to port business by implementing digital technologies. It is considered that digitalization is crucial for the future of port business. The goal of ports is to remain competitive and thus the ports are changing the traditional way of doing business through digitalization. It is likely that ports will become a kind of "digital hubs", connecting numerous stakeholders through numerous activities in which a large amount of information and documentation is exchanged.

The implementation of the Smart Port model stands out as the most prominent for the future of ports. The Smart Port model means that ports use digital technologies (such as Internet of Things, Blockchain, Artificial Intelligence, etc.) to increase the efficiency, effectiveness and safety of all port activities. A smart port gathers automation, intelligent infrastructures, better-educated individuals, skilled workforces to optimize the port operations, enhance the port resiliency, make port operations sustainable and guarantee safe and secure port operations [29]. Thus, ports are becoming more advanced in managing increased port traffic, more efficient and sustainable. The ultimate goal for ports is to become autonomous ports in interaction with other ports and to create a system of globally connected smart ports. The Smart Port model enables ports to face and overcome various challenges: spatial constraints, trade volume growth, sustainability pressures, safety and security [4].

In the last decade, digitalization has become one of the key issues in the EU, at the institutional, policy and funding level. According to the COVID-19 pandemic circumstances, the EU institutions have recognized even more the importance of the overall digitalization. Although the importance of digitalization is recognized, there is still a space for more projects regarding port digitalization i.e. Smart Port model implementation. According to the European Sea Ports Organisation (ESPO), share of the ICT/digital infrastructure in the port infrastructure projects was only 4% in the period 2014-2017 [19]. The EU institutions and organizations continuously take the initiatives towards promoting, policy creation and funding support for digitalization of the port business and implementation of the Smart Port model.

In this paper, the authors will provide a review of relevant EU institutions, organizations, policies, funds and projects related to Smart Port model implementation in the EU.

2. INSTITUTIONAL AND POLICY FRAMEWORK

The main EU institutions: the European Commision, the European Parilament and the Council of the EU, consider the ports as strategic partners for sustainable, competitive and smart European Union. These institutions have different roles in making policies and creating funds for supporting the Smart Port model implementation:

- The European Commission [24] is responsible for proposals of EU legislation and policies regarding projects. Furthermore, the European Commission implements decisions of the European Parliament and the Council of the European Union. Regarding the budget for projects implementation, the European Commission has triple role: sets European Union spending priorities as important task for creation of the funding programmes; prepares draft of annual and long-term budgets for approval by the Parliament and Council; supervises spending of budget i.e. funding.
- The European Parliament [25] is European Union's law (policies)-making body, elected directly by EU voters. Together with the Council of the European Union, adopts regulations and policies regarding each project area. Furthermore, the European Parliament, together with the Council of the EU, approves EU annual and long-term budgets such as ''Multiannual Financial Framework 2021-2027''.
- The Council of the European Union [23] represents the voice of EU member governments. Main tasks of the Council of the European Union are: adoption of EU laws, coordination of EU policies, adoption of the annual and long-term EU budget (with the European Parliament).

One of the first important policies regarding digitalization was in 2000, when the Lisbon Agenda was adopted. The goal was to make the EU the most competitive and dynamic knowledge-based economy in the world by 2010. Thus, the European Commission proposed three strategies (eEurope 2002 plans, eEurope 2005 and the i2010 strategy) to improve the deployment of Internet infrastructure and services (e-Government and e-Business) with aim to increase innovation and research spending in ICT. Digital policies were identified as a key for the ′′Europe 2020 Strategy′′ [18].

The European Commission has set six priorities for period 2019-2024 [13]: European Green Deal; Europe fit for the digital age; economy that works for people; stronger Europe in the world; promoting our European way of life; a new push for European democracy. Regarding the priority ′′Europe fit for the digital age′′, the European Union aims to make digital transformation of businesses and work, while also achieving climate-neutral Europe by 2050. The European Commission goal is to make the ongoing decade the European Union's "Digital Decade". In March 2021, the European Commission presented a vision of digital transformation by 2030, with four main points: digital transformation of businesses; digitalization of public services; secure and sustainable digital infrastructures; digital skills. The goal of the ′′Digital transformation of businesses′′ is to have 75% of EU companies using Cloud/AI/Big Data by 2030 [13].

One of the most important goals of the European Commission is the digitalization of the transport sector, including ports, so the Digital Transport and Logistics Forum (DLTF) was founded in 2015. The DLTF aims at supporting digitalization of transport and logistics. The aim is to identify challenges and areas where common actions in the European Union is needed, to provide recommendations and to help in the implementation of the recommendations. The Digital Transport and Logistics Forum assist the European Commission in implementing the European Union's activities and programmes. Furthermore, a task of the Digital Transport and Logistics Forum is to provide advice and technical expertise to the European Commission and in relation to the preparation of legislative proposals and policy initiatives as well as in their implementation [34].

In December 2020, the European Parliament and the Council of the EU adopted the ′′Multiannual Financial Framework 2021-2027′′ [2]. It is a long-term EU budget worth €1074.3 billion (in 2018 prices), including the integration of the European Development Fund. Together with the Next Generation EU recovery instrument of (worth €750 billion) enables €1.8 trillion of funding in the coming years for different policy areas.

On 19 February 2020, the European Commission launched a ′′Consultation on Artificial Intelligence′′, to create the White Paper on Artificial Intelligence – a European approach to excellence and trust: measures that will streamline research, foster collaboration between Member States and increase investment into AI development and deployment [16]. The European Commission has recently proposed new rules and actions for turning the European Union into global hub for trustworthy Artificial Intelligence (AI) [8]. The revised Coordinated Plan on AI was published in April 2021. It outlines a vision to accelerate, act, and align priorities with the current European and global AI landscape and bring strategy into action [5]. The European Union plans to achieve this by: development and uptake of AI in the European Union, making the European Union a place where AI thrives from the lab to the market, ensuring that AI works for people, society and economy.

The Directorate-General for Communications Networks, Content and Technology (DG CONNECT) is the European Commission department responsible to develop a digital single market and to generate smart, sustainable and inclusive growth in Europe [22]. The DG CONNECT has the responsibility to carry out European Commissions' policies regarding: digital economy and society; research and innovation; business and industry; culture and media [22].

The European Sea Ports Organization (ESPO), founded by the European Commission, drafted a ′′Memorandum of the European Sea Ports Organisation for the new Commission and European Parliament-Priorities of European ports for 2019 – 2024 [20].′′ In the Memorandum, ports are considered as hubs of innovation and digitalization. The smart ports can play a crucial role in enhancing efficiency, safety, security and environmental performance in the maritime transport and supply chain. Furthermore, the European Sea Ports Organization takes actions in collaboration with organizations such as The Federation of the European Private Port Companies and Terminals (FEPORT) and International Data Corporation (IDC). Actions are directed towards policy updating to enable ports to further develop. Thus, the European Sea Ports Organization submitted its proposals regarding the European Commission's review of the TEN-T Regulation 1315/2013. In the proposal, the European Sea Ports Organization declared that new TEN-T guidelines should be adapted to recognize the role of ports in digitalization and sustainability, not just ports classical role as part of maritime transport [21]. Main findings in the proposal that should be taken into consideration in updating the TEN-T network, are: market changes (such as volume growth, scale increases); new societal challenges (climate, air pollution, noise, increasing urbanisation); new needs in port business (digitalization, automation, e-commerce). In order to confirm the proposal, the European Sea Ports Organization has made an analysis of socio-economic impact of technological innovation and market-based developments in shipping on the port sector. The analysis provided an insight in the current situation in container ports and highlighted the fact that adaptation to market development and technological innovation requires major investments in equipment as well as continuous reskilling and upskilling of ports workers [22].

In May 2021, European Parliament adopted a report ''Shaping the digital future of Europe: removing barriers to the functioning of the digital single market and improving the use of AI for European consumers'', calling on the European Commission to identify challenges posed by the digital transition and especially take advantage of the opportunities of the digital single market, improve the use of Artificial Intelligence and support digital innovation and skills [17].

The three EU institutions, in 2020, also adopted the first joint conclusions on objectives and priority policies for the entire legislative cycle. Actions in the coming years will be guided by the legislative priorities set out in the ''Joint Declaration for 2021 and the Joint Conclusions on the 2020-2024 Objectives and Priority Policies'' [15]. In March 2021, the Commission presented a vision for European Union digital transformation by 2030. This vision contains four main components: digital transformation of businesses; digital skills; secure and sustainable digital infrastructures; digitalization of public services [9].

3. FUNDING AND PROJECT FRAMEWORK

The funding structure in the European Union budget is focused on specific priority areas. Thus, funding related to the implementation of the Smart Port model, is included for example in the digitalization area, development of the transport i.e. port sector, transport mobility, innovation, etc. The concrete funding opportunities and projects of the European Union institutions regarding digitalization i.e. Smart Port model implementation are presented hereafter. The funding framework is analysed form the aspect of the 2021-2027 financial perspective, because future projects will find funding opportunities in programmes i.e. funds prepared for this period. In the project framework analysis, concrete programmes i.e. funds are mentioned taking into consideration that projects are closed or ongoing and thus already received funding.

3.1. Funding framework

The European Parliament and Council of the European Union adopted the ''Multiannual Financial Framework for 2021-2027 period (MFF 2021-2027)'' [2]. It is long-term budget for 2021-2027 with worth of €1.074 trillion. The European Union aims to boost up investments in: digital transformation, research and innovation, strategic infrastructure and the Single Market, as these investment areas are considered as crucial for the future growth of the European Union. The new long-term budget will operate through several programmes i.e. funds, of which the most relevant for this research are described hereafter.

The Digital Europe Programme (DEP) is a new European Union funding programme focused for application of digital technologies in businesses and public administrations and making digital technologies more available to citizens. The worth is €9.2 billion in current prices [12]. The Digital Europe Programme is the central programme of digital transformation of the European Union. Main funding areas are [12]:

- supercomputing and data processing capacities;

- building-up and reinforcing core artificial intelligence (AI) capacities (e.g. data resources and libraries of artificial intelligence algorithms) and make them accessible to all businesses and public administrations;
- improvement of the cybersecurity,
- improvement of digital working skills;
- expansion of use of digital technologies in EU's society and economy.

The Connecting Europe Facility – Digital (CEF – Digital) will support project initiatives in Trans-European networks and infrastructures in the sectors of transport, telecommunications and energy, worth of €2 billion in current prices. Main funding areas are [7]:

- very high-capacity networks (including 5G systems);
- very high-quality local wireless connectivity in local communities that is free of charge and without discriminatory conditions;
- uninterrupted coverage with 5G systems of all major transport paths (including the Trans-European transport networks);
- upgrade of existing backbone networks including submarine cables;
- digital connectivity infrastructures related to cross-border projects in the areas of transport or energy and/or supporting operational digital platforms in transport or energy infrastructures.

Horizon Europe is the European Union's next funding programme for research and innovation that will continue the work of Horizon 2020, worth €105.8 billion in current prices. The first strategic plan sets out the priority investments in the programme's first 4 years [14]:

- development of key digital, enabling and emerging technologies to accelerate and the digital and green transitions;
- making European Union the first digitally enabled circular, climate-neutral and sustainable economy;
- improved managing of ecosystems, biodiversity and natural resources;
- creating a more inclusive, democratic and to threats responsive European Union society.

The Horizon Europe includes a specially dedicated budget for "Digital and industry" aiming in research and high-end innovation in digital technologies (artificial intelligence and robotics, next generation internet, high performance computing and big data, key digital technologies). In the funding sum, around 20% is for predicted for digital projects. Furthermore, some funding areas in Digital Europe Programme and Horizon Europe seems like overlapping, but outputs are different and complementary. The Digital Europe Programme will focus on large-scale digital capacity and infrastructure building, while Horizon Europe will be supporting research and technological development [11].

For example, the projects regarding AI are identified by European Commission as one of the most important for funding through Digital Europe and Horizon Europe programmes. The European Commission plans to invest €1 billion per year in AI. In the newly adopted Recovery and Resilience Facility, €134 billion will be available for digitalization projects [5]. For Horizon Europe, the European Commission proposed to invest €15 billion in the 'Digital, Industry and Space' cluster, with AI related activities as key ones to be supported. As part of Digital Europe Programme, the European Commission proposed to invest almost €2.5 billion in deploying data platforms and AI applications.

The European Commission has made a budget available within the Horizon 2020 Green deal programme'' for research of opportunities to increase the sustainability of logistics operations in ports and airports. Close to € 25 million of this funding has now been awarded as a research grant to the 45-member consortium headed by the Port of Rotterdam Authority to promote smarter, zero-emission transport in ports. The results of the various pilot projects and studies will be shared with other European ports, knowledge institutes and companies. Specifically, the EU grant will be used to execute 10 pilot and demonstration projects that focus on sustainable and smart logistics in port operations.

In the ''New Regional Development and Cohesion Policy 2021-2027'' resources for regional projects funding will be mainly available for these two objectives: Smarter Europe through innovation, digitalization, economic transformation and support to small and medium-sized business; Greener and carbon free Europe [27]. With a budget of €8.1 billion, the 6th generation of Interreg Programme continues to support territorial cooperation across European Union (cross border, transnational and interregional) [6]. For example, ''Interreg Euro-MED Programme 2021-2027'' is under negotiations. It will have three main priorities:

- Smarter MED: developing and enhancing research and innovation capacities and the uptake of the advanced technologies.
- Greener MED: protection of the nature and reduction of the pollution.
- MED Governance: thematic network projects (horizontal projects).

Furthermore, the Interreg ADRION Programme is also under negotiations. Objectives regarding digitalization i.e. Smart Port model are: smarter European Union by promoting innovative and smart economic transformation; more connected European Union by enhancing mobility and regional ICT connectivity [26].

3.2. Smart Port projects

The ''SMART-PORT project - Action plan towards the Smart Port Mediterranean Area'', has been funded from the 2007-2013 MED Programme [33]. The overall objective of the SMART-PORT project was to analyse the situation of Mediterranean container ports based on the "smart-port" trends and to identify steps necessary to enhance the leading role of the Mediterranean container ports rather than the ports of Northern Europe. The contribution of the project was in following:

- map of the smart port criteria: definition of the criteria that shape the Smart Port model: operational, energy, and environmental aspects;
- status Quo of the Mediterranean ports: the starting point for a base for strategies at individual and general level (MED area scope);
- map of competitive advantages and disadvantages: map of barriers & gaps associated to the different factors that determine the Smart Port trends, as a basis for action plan at European level to achieve the Smart Port challenge;
- strategic action plan towards the smart port concept, aimed at exploiting the existing potential and at the same time, contributing to the decision-making process.

The PortForward Project- Towards a green and sustainable ecosystem for the EU Port of the Future, has received funding from the Horizon 2020 research and innovation programme [32]. The PortForward project aims at proposing a holistic approach that will lead to a smarter, greener and more sustainable port ecosystem, including the following: the introduction of an Internet of Things (IoT) concept for port assets (infrastructure, vehicles, cargo, people); the socio-economic analysis of the port, surrounding area, port-city and the rest of logistics value chain; the Virtual Port concept, Augmented Reality for port operations. Technologies included in the project are:

- IoT concept for port assets;
- sensors, cameras and multi-modal tracking devices;
- one seamless, versatile and secure IoT network;
- remote management and intelligent maintenance tool;
- virtual Port tool for centralized control and alternative visualisations;
- smart logistics platform with a decision support system (DSS);
- environmental and energy monitoring/ optimisation system;
- augmented reality (AR) for pilot assistance and remote assistance to workers/operators.

The ''PIXEL project- Port IoT for Environmental Leverage'' has received funding from the Horizon 2020 research and innovation programme [30]. The main pillars of the PIXEL project are:

- Smart Port Solutions: ICT solutions which improve information flows between ports and port communities.
- Green Port Solutions: green technologies for reducing negative environmental impacts and sustainable port operations.
- Interconnected Port Solutions: different modes of transport and integration of technologies for better monitoring and control of the freight flows.

The PIXEL project has specific research and innovation objectives [31]:

- IoT-based connection of port resources, transport agents and city sensor networks;
- aggregation and homogenization of multi-source heterogeneous data-methodology and tools for standardisation of data from heterogeneous sources;
- operational management dashboard to enable a quicker, more accurate and in-depth knowledge of port operations;
- modelling and simulation of port-operations processes for automated optimisation;
- predictive algorithms: development of predictive algorithms for selected port-operative process;
- methodology for quantifying, validating, interpreting and integrating all environmental impacts of port activities into a single metric called the Port Environmental Index (PEI);
- guidelines for avoiding possible environmental and health effects of port activities-statistical analysis and visualization of the obtained data in a GIS environment will be addressed.

The Connect2SmallPorts project - South Baltic Small Ports as Gateways towards Integrated Sustainable European Transport System and Blue Growth by Smart Connectivity Solutions'', has received funding from the Interreg South Baltic Programme 2014 – 2020 [28]. The project goal was development of South Baltic small and medium ports through implementation of digital solutions. The project focus on two digital technologies: Internet of Things (IoT) and Blockchain. IoT is basically connects different items (containers, port equipment) to an online network. Blockchain allows paperless administration such as contracts. The improved quality of transport services in small ports is achieved through innovative and environmentally sustainable transport solutions [28]:

- Digital Auditing Tool for evaluation and improvement of port's performance in digitalization and cargo transport services;
- Blockchain and IoT Strategy for small port and terminal applications for better transport performance and sustainability;
- 5 pilots implemented in 5 SB ports for integration and valorisation of Blockchain and IoT strategies;
- digitalisation-driven sustainable value creation models for small ports: future digitalisation and benchmarking index; Blockchain and IoT strategies for SB ports integrated in education and training curricula; a yearly Digital Forum Small Ports with Award.

The DataPorts project - A Data Platform for the Connection of Cognitive Ports, has received the funding from Horizon 2020-EU.2.1.1. – INDUSTRIAL LEADERSHIP – Leadership in enabling and industrial technologies – Information and Communication Technologies (ICT) [3].The DataPorts will provide a Data Platform in which transportation and logistics companies connected to ports will be included. The project is focused on creation of a secure Data Platform that allows sharing the information not only between port agents but also between other ports. The Data Platform should be secure for data exchange, with access permits and contracts. Possibilities of using new Artificial Intelligence and cognitive services will be explored. DataPorts platform aims at providing ports secure and private aware-environment where data coming from different sources can be shared in a trusted and reliable way, in order to get real value from those data, providing a set of AI and cognitive tools to the port community.

The COREALIS project - Capacity with a pOsitive enviRonmEntal and societAL footprInt: portS in the future era, has received funding from the Horizon 2020 research and innovation programme [1]. The COREALIS project aims at proposing of strategic, innovative framework, supported by disruptive technologies, (Internet of Things, data analytics, next generation traffic management and emerging 5G networks), for cargo ports for better response on traffic and environmental challenges. The innovations will be implemented and tested in real operating conditions in five Living Labs: Port of Piraeus, Port of Valencia, Port of Antwerp, Port of Livorno and Port of Haminakotka. Goals of the projects will be achieved through the implementation of a 3-step 'Stakeholder driven approach' methodology: identification of port requirements (technical, operational, societal, environmental, legal, security etc.); technical design; development of innovations- innovations Impact Assessment and Living Labs full-scale implementation [1].

4. CONCLUSION

The digitalization i.e. Smart Port model implementation is recognized by EU institutions and organizations as crucial for future development of the port business. Overall digitalization is set out as priority funding area for next ''Digital decade'' in the EU. The EU institutions (European Commission, European Parliament and Council of the EU) adopted various policies which regulate funding support for the projects regrading digitalization i.e. Smart Port model implementation. Furthermore, various organizations in transport, port and logistics sector (European Sea Ports Organisation, The Federation of the European Private Port Companies and Terminals, etc.) continuously collaborate with the EU institutions to promote ports role in the digitalization and sustainability and to revise the TEN-T network according to new role of the ports. Various Smart port projects have been provided or currently are providing: the SMART-PORT, the PortForward, the PIXEL, the Connect2SmallPorts, the DataPorts and the Corealis. Project have received funding mostly from the Horizon 2020 research and innovation programme; industrial leadership, Interreg Med and South Baltic 2014-2020. In these projects, different aspect of the Smart Port has been analysed: smart port criteria, smart port methodology, evaluation of the smart port performance, data standardisation, data platforms for port community, living labs and concrete application of the digital technologies, etc.

In the new financial perspective 2021-2027, programmes and funding open more opportunities for application of the Smart Port projects: Digital Europe Programme, the Connecting Europe Facility – Digital, Horizon Europe, Regional Development and Cohesion Policy; new Interreg Med and Adrion Programmes. All funding resources are mostly focused on implementation of digital technologies and digital transformation, thus enabling project proposals for smart port development.

REFERENCES

[1] COREALIS project, Available online, https://www.corealis.eu/#about [Accessed 26-Jun-2021]

[2] Council of the European Union, Long-term EU budget 2021-2027 and recovery package, Available online: https://www.consilium.europa.eu/en/policies/the-eu-budget/long-term-eu-budget-2021-2027/ [Accessed 18-Jun-2021]

[3] DataPorts project, Avalaiable online: https://dataports-project.eu/ [Accessed 25-Jun-2021]

[4] Deloitte Port Services, Smart Ports- Point of View, Available online: https://www2.deloitte.com/content/dam /Deloitte/nl/Documents/energy-resources/deloitte-nl-er-port-services-smart-ports.pdf [Accessed 17-Jun-2021]

[5] European Commission, A European approach to Artificial intelligence, Available online: https://digital-strategy.ec.europa.eu/en/policies/european-approach-artificial-intelligence [Accessed 18-Jun-2021]

[6] European Commission, Commission welcomes the adoption of €373 billion Cohesion policy legislative package 2021-2027, Available online, https://ec.europa.eu/regional_policy/en/newsroom/news/2021/06/25-06-2021-commission-welcomes-the-adoption-of-eur373-billion-cohesion-policy-legislative-package-2021-2027 [Accessed 22-Jun-2021]

[7] European Commission, Connecting Europe Facility (CEF2) Digital, https://ec.europa.eu/digital-single-market/en/connecting-europe-facility-cef2-digital [Accessed 21-Jun-2021]

[8] European Commission, Europe fit for the Digital Age: Commission proposes new rules and actions for excellence and trust in Artificial Intelligence, Available online: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_1682 [Accessed 18-Jun-2021]

[9] European Commission, Europe's Digital Decade: digital targets for 2030, Available online: https://ec. europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en [Accessed 21-Jun-2021]

[10] European Commission, Importance of ports for economic recovery and jobs, Available online: https://ec.europa.eu/commission/presscorner/detail/en/MEMO_12_317 [Accessed 17-Jun-2021]

[11] European Commission, The 2021-2027 Multiannual Financial Framework; Digital shines through in the EU's long-term budget, Available online, https://ec.europa.eu/digital-single-market/en/2021-2027-multiannual-financial-framework-digital-shines-through-eus-long-term-budget [Accessed 21-Jun-2021]

[12] European Commission, The Digital Europe Programme, Available online, https://digital-strategy.ec.europa.eu/en/activities/digital-programme [Accessed 21-Jun-2021]

[13] European Commission, The European Commission's priorities 2019-2024, Available online: https://ec.europa.eu /info/strategy/priorities-2019-2024_en [Accessed 18-Jun-2021]

[14] European Commission, The first Horizon Europe strategic plan (2021-2024), Available online: https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls /horizon-europe/strategic-plan_en [Accessed 21-Jun-2021]

[15] European Commission, The joint priorities of the EU institutions for 2021-2024, Available online: https://ec.europa.eu/info/strategy/strategic-planning/joint-priorities-eu-institutions-2021-2024_hr [Accessed 20-Jun-2021]

[16] European Commission, White Paper on Artificial Intelligence – a European approach to excellence and trust, Available online: https://digital-strategy.ec.europa.eu/en/consultations/white-paper-artificial-intelligence-european-approach-excellence -and-trust [Accessed 18-Jun-2021]

[17] European Parliament, Digital transformation: importance, benefits and EU policy, Available online: https://www.europarl.europa.eu/news/en/headlines/society/20210414STO02010/digital-transformation-importance-benefits-and-eu-policy [Accessed 20-Jun-2021]

[18] European Parliament, EU policies - Digital transformation, Available online: https://www.europarl.europa.eu /RegData/etudes/BRIE/2019/633171/EPRS_BRI(2019)633171_EN.pdf [Accessed 18-Jun-2021]

[19] European Sea Port Organisation, The ınfrastructure ınvestment needs and fınancıng challenge of European ports, Available online: https://www.espo.be/media/Port%20Investment%20Study%202018_FINAL_1.pdf [Accessed 17-Jun-2021]

[20] European Sea Ports Organisation, Prıorıtıes of European ports for 2019 – 2024; Memorandum of the European Sea Ports Organisation for the new Commission and European Parliament, Available online: https://www.espo.be/media /Memorandum%20ESPO%20FINAL%20Digital%20version.pdf [Accessed 19-Jun-2021]

[21] European Sea Ports Organisation, The Ten-T review must recognize the new roles of ports, Available online: https://safety4sea.com/espo-the-ten-t-review-must-recognize-the-new-roles-of-ports/ [Accessed 20-Jun-2021]

[22] European Union, Communications Networks, Content and Technology, Available online: https://ec.europa.eu/info/ departments/communications-networks-content-and-technology_en [Accessed 19-Jun-2021]

[23] European Union; Institutions and bodies, Council of the European Union, Available online, https://europa.eu/ european-union/about-eu/institutions-bodies/council-eu_en [Accessed 17-Jun-2021]

[24] European Union; Institutions and bodies, European Commission, Available online: https://europa.eu/european-union/about-eu/institutions-bodies/european-commission_en [Accessed 17-Jun-2021]

[25] European Union; Institutions and bodies, European Parliament, Available online, https://europa.eu/european-union/about-eu/institutions-bodies/european-parliament_en [Accessed 17-Jun-2021]

[26] Interreg ADRION, towards the new Adrıon: a vıew ahead on the next programmıng perıod 2021-2027, https://www.adrioninterreg.eu/index.php/about-program/programme/towards-the-new-adrion-a-view-ahead-on-the-next-programming-period-2021-2027/ [Accessed 22-Jun-2021]

[27] Interreg Mediterranean, ''Interreg Euro-MED Programme 2021-2027, Available online: https://interreg-med.eu/about-us/futureinterregmedprogramme/ [Accessed 22-Jun-2021]

[28] Interreg South Baltic, Available online, https://southbaltic.eu/-/connect-2-small-ports [Accessed 25-Jun-2021]

[29] Molavi, A., J. Lim, G., Race, B., A framework for building a smart port and smart port index, Internatıonal Journal of Sustaınable Transportatıon, 2020, VOL. 14, NO. 9, 686–700, Doi: https://doi.org/10.1080/15568318.2019.

[30] Pixel Project, Available online: https://pixel-ports.eu/ [Accessed 23-Jun-2021]

[31] Pixel Project, Objectives, Available online, https://pixel-ports.eu/?page_id=520 [Accessed 24-Jun-2021]

[32] Port Forward project, Available online, https://www.portforward-project.eu/?avada_portfolio=dissemination-material [Accessed 23-Jun-2021]

[33] SMART-PORT project, Available online: https://keep.eu/projects/17593/Action-plan-towards-the-Sma-EN/ [Accessed 23-Jun-2021]

[34] The Motorways of the Sea- digital Multimodal Platform, EU Commission for the digitalization of Transport Sector, Available online: https://www.onthemosway.eu/eu-commission-for-the-digitalization-of-transport-sector/ [Accessed 18-Jun-2021]

[35] United Nations Conference on Trade and Development, Available at: https://shop.un.org/series/review-maritime-transport [Accessed 17-Jun-2021]

SOFTWARE MANAGED HYBRID WIRELESS NETWORKS IN MARITIME ENVIRONMENT

Toni Besjedica
University of Dubrovnik, Croatia
Department of Electrical Engineering and Computing
E-mail: toni.besjedica@unidu.hr

Krešimir Fertalj
University of Zagreb, Croatia
Faculty of Electrical Engineering and Computing
E-mail: kresimir.fertalj@fer.hr

Ivona Zakarija
University of Dubrovnik, Croatia
Department of Electrical Engineering and Computing
E-mail: ivona.zakarija@unidu.hr

UDK 004.7:654.16
654.16:656.61

Summary

Hybrid networks are relatively new term in communication technologies that integrates all radio frequency and optical wireless networks in one domain. This paper considers a software defined network comprised of LiFi and WiFi access points (APs) to be used in maritime environment (e.g. LNG terminals and carriers). LiFi can provide a secure connection in areas where standard RF (WiFi) is forbidden or other way impossible to use due to physical restrictions of radio waves. LED light sources can be easily upgraded to incorporate LiFi communication as LiFi AP is a network enabled LED lamp thus enabling communication (e.g. internet) in areas of LNG carrier of terminal where WiFi was not an option. In addition LiFi technology can be used to transmit data throw the sea surface using high power LEDs thus enabling communication between vessels or drones.

Keywords: hybrid networks, LiFi, visible light communication, software defined network

1. INTRODUCTION

Light Fidelity, LiFi, is a relatively new form of wireless communication technology. It uses light to send data. LiFi has higher data speeds than WiFi. In the lab, LiFi reached speed of 224 Gbps. When tested in real conditions, factory in Estonia, LiFi technology achieved rates of 1 Gbps.

The man behind this project is professor Harald Hass: "All we need to do is fit a small microchip to every potential illumination device and this would then combine two basic functionalities, illumination, and wireless data transmission. In the future we will not only have 14 billion light bulbs, we may have 14 billion LiFis deployed worldwide for a cleaner, greener, and even brighter future" (Harald Hass Ted Talk 2011).

Professor Hass proved that data can be transmitted over the light spectrum. LiFi uses infra-red and ultra-violet (visible light) waves to send/ receive data. Infra-red and ultra-violet spectrums can carry more information than radio frequency waves which makes the backbone of LiFi speeds. LiFi can be thought of as a light based WiFi which instead of WiFi modems, uses transceiver-fitted LED lamps that can bring light in a room as well as transmit and receive information. Since basic lights are utilized, there can technically be any number of access points.

At present, LiFi technology uses light from light-emitting diodes (LED) to impart data. LEDs are very known around the world for their efficiency, ecology, and life span. These LEDs can be turned into wireless access points. LED lights are a semiconductor light source, which makes easier to alter the electricity supply to the bulb to dim it or brightener it. The current in the LED bulb in flicked on and off at very high speed, in fact this functions similar to Morse code using 1s and 0s. The flicking happens at a speed too fast for the human eye to notice, therefore safe for humans and animals. If the lights are off LiFi will continue because it can work on low light level that cannot be recognized by the human eye. To access the LiFi network you simply need a device to detect the light signals, with part to translate the light signals into information.

On the other hand WiFi uses radio frequency, a technology with limited and licenced space that is reaching its max capacity.

Quite possibly the most charming features of LiFi is that it utilizes VL spectrum. The VL spectrum is 10 000 times bigger than the radio frequency spectrum and is unregulated. So you needn't bother with a permit to exploit the light spectrum.

LiFi also does not emit electromagnetic interference which makes it more suitable for highly sensitive areas where electromagnetic interference can affect communication.

Data goes into an LED light bulb which has a module with signal processing technology, data is then pulsed at high non-visible rate to the photodetector. The pulses are interpreted to an electrical signal, which is then converted back to binary data. These LED lights can be networked, so multiple users can access data using a single LED light or move from one LED light to another.

LiFi has faster speeds than WiFi, but it has short range. This is true especially when you step further away you are from the light source. Even though it is not necessary to be under the LED light to access LiFi because it can use light reflections on surfaces, including walls to transmit data with speeds averaging at 70 MB/s. As we know light cannot penetrate walls that limits the range of LiFi, but it also makes the technology much more secure.

It ensures that users can be limited within specific the area of accessibility. Defence and technology industry are very interested in development due to this physical constraint of LiFi technology.

Because of the speed LiFi can reach, and its limits, the technology will work alongside cellular and WiFi technology as an additional option for connectivity. LiFi can be utilized to redirect heavy traffic from cellular and WiFi networks.

security of the information transfer is as of now quite possibly the main concern. Visible light can be reflected however for the most part it does not penetrate materials such as walls which makes it a safety feature. WiFi on the other hand is vulnerable to outside factors as it penetrates through most walls and obstacles therefore it can be easily intercepted.

LiFi has another big problem due to the intensity of an external source of illumination such as sun.

If this external source has greater intensity, transmission of data by the LEDs is washed out. The receiver cannot transmit back or provide feedback to the transmitter. For this reason LiFi cannot be a standalone technology an must be incorporated, for now, with LTE and WiFi.

The agreeable acknowledgment of Haas to use light as a replacement radio-waves thus enhancing the usable band colossally and simultaneously making the message transmission more secure and less harmful has a potential impediment to be explored: although light emitted in this way is not perceived by the human eye, it is still uncertain whether the brain is aware of the fluctuation and if so to what extent.

2. LiFi NETWORKS

LiFi is a part of VLC which mostly is focused on point-to-point communication. VLC research assumes that the visible light spectrum is used for both uplink and downlink communication. LiFi envelops more extensive networked systems, including multiuser, bidirectional, multicast, or broadcast communication. Even though it uses the VL spectrum for downlink, LiFi uses the infrared spectrum for the uplink. Essential system components are illustrated in Fig.1. LiFi networks are designed from the start to work seamlessly with RF wireless networks in order to provide efficient load balancing and extended capacity in heterogeneous networks. LiFi network incorporates multiple access points (APs) forming ultrasmall cellular networks. This in turn provides high data-density wireless communication services to multiple users simultaneously [9].

LiFi network supports handover when users move between different areas. Bidirectional connections are established between an AP and user equipment (UE) regardless of serving numerous users simultaneously. Backhaul connections between APs and the network gateway are essential to provide AP cooperation or to connect to the external network [4]. These backhaul connections can be provided by fiber optic cable, Ethernet or powerline [4,14]. LED as a downlink is used because of its increasing popularity and it has been shown that multi-Gbps transmission via LEDs is possible [10].

In a LiFi network, an uplink is responsible for sending transmission acknowledgements, channel state information (CSI), and uploading files. Since using visible light in the uplink may cause distractions to the mobile user it has been decided to use the infrared spectrum. This has the extra advantage that there is no obstruction among uplink and downlink and simultaneous communication. This part of LiFi communication is still in development [2,6].

Besides, various RF-based communication technologies can also be considered for uplink such as Bluetooth or WiFi [16]. These systems are available, but as they may cause interference with existing RF systems this model is still in early stages of development. RF/VLC hybrid communication system with VLC for downlink only can offload a lot of information traffic [6] and to display low latency [20]. A complete LiFi network composed of handover, multiple access, and co-channel interference (CCI) coordination is displayed in Fig.1. There are two types of handover: horizontal handover and vertical handover. In horizontal handover UE is changed between different APs in the same technology (e.g. radio frequency) where as in vertical handover UE is changed between APs with different technology, for example: user passes from WiFi to LTE.

When the user enters the coverage of numerous LiFi AP vertical handover LiFi AP can be made to relieve the WiFi network for more productive activity which in end ensures less packet collisions [21]. Research of the horizontal handover scheme in LiFi networks has been carried out by Vegni [21]. Beside horizontal, vertical handover must be used to ensure continuous connectivity. Similar scheme based on the prediction of uncertainty metrics has been proposed by Shufei [21] which shows a huge decrease in transmission delays.

Moreover, because of the more modest cell size and blockage issues of LiFi networks, the recurrence of handover increases significantly which is ideal for implementation of soft handover or handover skipping schemes (techniques that enable handover between non adjacent APs also, overlook APs causing pointless handovers). Fast link switching schemes with the use of pre-scanning and received signal strength (RSS) prediction can be used to improve the robustness of LiFi networks[21]. Interference will happen in wireless links using the same transmission resource, the users in adjacent cells may also share the same transmission resource. This is called CCI. Another possibility is that transmission resource is reused by users within the same cell, called intra-cell interference. Intra-cell interference is dealt with by utilizing orthogonal multiple access techniques. CCI is mitigated by proper interference coordination techniques.

To mitigate this problem cell-centric architecture can be used to establish a multitier heterogeneous network with extremely dense cells. This approach dynamically adjusts the network topology based on user demand, if there is no user within the coverage of a LiFi AP, it turns of communication module and acts as ordinary light source avoiding interference to neighboring cells. The inspiration for this methodology in LiFi comes from the extreme shrinkage of cell sizes to the scope of 1 to 2 m in range.

Load of an AP varies significantly in these systems [21], like in user-centric architecture, the original cells at APs are turned into virtual cells centered on major clusters of users. For this to be possible dynamic merge and disaggregation of cells is required with knowledge of user location and user positioning. In addition to optimization of communication performance this results in enhanced energy efficiency.

To increase the downlink transmission speed of LiFi networks, optical wireless systems using one-directional coherent signal transmission in combination with very narrow beam steering has been considered.

A recent study has announced potential speed of over 400 Gbps [13].

Different experimental study transmits centrally processed coherent optical signals through optical fiber to beam-steering system and then to end users wirelessly. Uplink connection is accomplished using RF. Beam-steering techniques can improve spatial reuse in LiFi networks, however that would require extensive work to overcome some limitations like precise and simple user tracking especially when the LoS is lost, also optical fiber connections which are required for high-speed backbone connections are costly not to mention that uniform lighting is not supported within these designs.

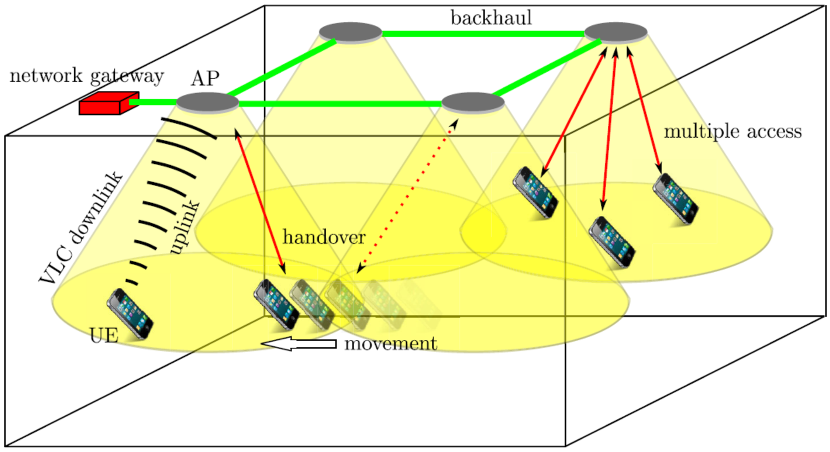


Figure 1 LiFi network with user handover

3. SDN HYBRID NETWORKS

A software-defined network (SDN) is relatively new term in networking used to explain a hybrid network composed of LiFi, WiFi and LTE APs. Smartphones or devices with 5G capability and with multiple interfaces, can choose the way of communication within different wireless networks. Device can download music through the WiFi (RF network) but stream high definition (HD) videos using LiFi interface. Another possibility is to make on-the-move voice over internet protocol (VoIP) calls through the LTE interface. Hybrid network has constant changes in resource availability, users mobility, traffic volume, connection, duration and service requirements.

For this reason, network must be planned with dimensioned resources and autonomous and adaptive services [21]. Another requirement is to support intelligent traffic routing in the user plane to deal with UE mobility during active communications.

A centralized SDN architecture provides a platform that can meet these requirements [12], [13]. As seen in Fig. 2 [14], the SDN architecture decouples the control plane and data plane. The information displays network events (for example, AP failure and service disruption), traffic statistics, and payload analysis.

The southbound part of SDN gathers it, and the northbound part advertises it on a regular basis to the application plane [12].

The controller in SDN applications manages OpenFlow (OF) rules in the various APs to enable the data plane services. A suitable traffic engineering (TE) strategy can allow intelligent traffic flows routing and network function virtualization (NFV) modules by using the centralized view of the network state [15].

This is shown when there is congestion or failure in one or more APs, controller routes traffic flows to others in order to increase network resource efficiency and to support provisioning for mission-critical applications [9].

SDN architecture can provide a network platform which can embody the integration of RF and VLC in line with the 5G standards [7], [8]. Controller is connected with its east and west interfaces to the 5G core network.

This paper shows a concept of SDN network composed of LiFi, WiFi and LTE interconnected through the SDN architecture shown in Fig. 2.

Wireless network SDN control plane implementation is more complicated than wired optical network SDN control plane implementation [16]. Physical limitations such as channel gain fluctuations, bandwidth availability and granularity, heterogeneous multiuser access, and flow routing reconfiguration speed must all be taken into account.

Following chapter explains queueing model on north and south bound interfaces of controller which is necessary for heterogeneous wireless networks to work seamlessly under SDN architecture and to provide efficient service provisioning.

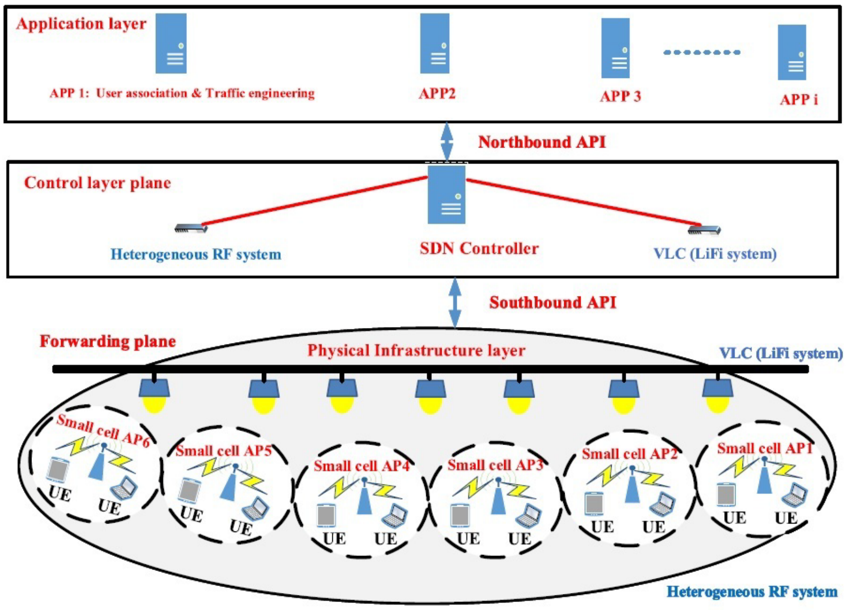


Figure 2 Application layers of SDN network

3.1. Queuing model for SDN network

The SDN enabled network is composed of data (forwarding), control and application layers. Data layer consists of LiFi, WiFi and LTE APs which are managed by SDN controller that is located in control layer. Orthogonal frequency-division multiple access (OFDMA) protocol is used to allocate resources in downlink channels of LiFi and LTE APs.

Term wireless resource describes a slot in time and frequency domains, and makes the smallest resource unit which some device can get from the network. S denominates average number of slots available for data transmission in downlink within time frame, T_F.

Channel states are shown by a number of modulation and coding schemes $(MCS)_i$, $1 \leq i \leq I$. Typically UE uses the MCS_i to transmit a number of bits, bi, per slot with probability p_i, for each frame time-step, T_F.

Open vSwitch [17] is used to run the APs, which enables OpenFlow (OF).

Tree topology is used to connect the controller via OF- switch shown in Fig.2 where as a set of northbound REST APIs enables communication between application layer and control layer thus supporting various applications like user association, traffic engineering, security, access control and many others shown in Fig.2.

Likewise southbound APIs enable communication between data and control layer supporting global view of network thus representing state of resources and connectivity as well as setting traffic forwarding rules for the routing tables in APs. When APs receive data flow, it sends info to the controller to set forwarding rules in switches [18].

General service distribution (G) is set as variation in time and space in the downlink channels of APs. AP has a buffer size K packets, when UE connects downlink flows can be interpreted as Markovian (M) Poisson distribution, enabling the use of M/G/1/K queuing model [19] to describe the networking operations of APs in data layer shown in Fig.3.

Likewise, controller manages N switches in data layer M/G/1/K/N queuing model is used to describe traffic handling in southbound interface of SDN controller. Traffic arrives at switch in Poisson distribution at rate λ_s.

Exponential distribution with average $\frac{1}{\mu s}$ is defined as service time of switch while as service time of controller is exponential with average rate $\frac{1}{\mu c}$.

If we define a pre-set rules to the switch flow will have a forwarding probability of $\overline{\phi s} = 1 - \phi s$, but if we don't have pre set rules a packet is first directed to the controller that has a probability ϕs to create a forwarding rule.

Generally traffic rate from switch to controller and back is expressed $\phi s \lambda s$ and $\psi s \phi s \lambda s$, respectively where ψs describes probability of traffic without pre-defined rules.

There is always a possibility that more than one API needs to use same resource which was at one point advertised as available. This retrial access usually starts when network has a huge volume of requests from SDN APIs on northbound interface or insufficient resources in data layer.

The trigger for this behaviour are applications that require network state updates or resources. In order to mitigate problem M/M/1 retrial queue with geometric loss and feedback [20] is used to model APIs access in data layer trough northbound interface. λ_n defines arrival rate of APIs requests through interface. α is probability of requests that enter retrial queue and $\overline{\alpha} = 1 - \alpha$ defines drop probability of these requests.

Requests in retrial queue have exponential distribution with average rate $\frac{1}{v}$ to access network resources. $\overline{\beta} = 1 - \beta$

is probability that API that requires one service leaves the controller where as if it requires more services and rejoins the retrial queue it has probability of β.

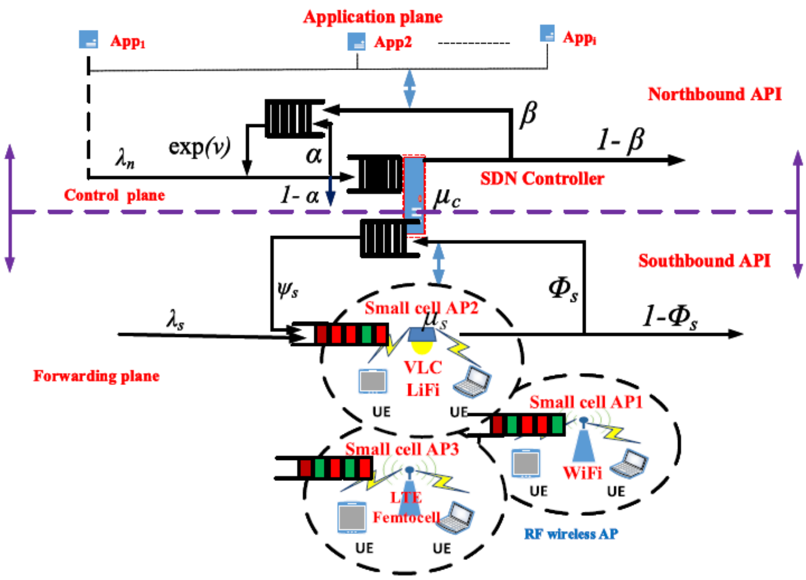


Figure 3 Model of queue distribution in SDN network

4. MARITIME USAGE OF LIFI TECHNOLOGY

As shown in chapters above the proposed model can be implemented in ships and terminals in following manner: replacing the existing (non LED) light sources with more efficient LEDs which will result in less power consumption as well as serving as AP for the future hybrid network. Implementing the proposed model first in areas of the ship were standard WiFi connection is not possible due to restrictions or physical properties of the area (e.g. thick metal walls). Implementing LiFi will enhance the speed and connectivity of personnel on board and will result in more efficient and secure work environment. Fig.4 shows one of the existing LiFi product kits on the market which can be easily implemented in existing ship infrastructure.

Figure 4 Hyperion LiFi kit

Source: https://www.hyperiontechs.com/product/1083/

Another possibility of LiFi usage on ships is to monitor ship functions. In the existing system, the parameters that are monitored using the sensors in the ship are transmitted through radio frequency communication. It includes radio telephone, automatic radio telegraph equipment, mega phone. Radio spectrum is congested but the demand for wireless data doubles each year. The quality of service (QoS) of specific networks in large ship environments should be tested to see if it can handle not only a sustained traffic load, but also anticipated traffic bursts [11]. This system lacks reliability of data, uses already congested spectrum which results in insufficient bandwidth and possible data loss. Proposed LiFi system uses transmitter module with an LED light to stream the data at high rate. Photodetector in the receiver module is used to capture the light. The receiver converts the received light signal into audio output that is accessed using a speaker. The LiFi transmitter is placed in the work areas in the ship and receiver is devised in captain's cabin to receive reliable data instantaneously. There is a number of sensors that LiFi system can be used to control such as : gas sensor, fire sensor, water leakage sensor, pir sensor(motion detection). Fig. 5 shows a diagram of the proposed system that can be implemented into LiFi network.

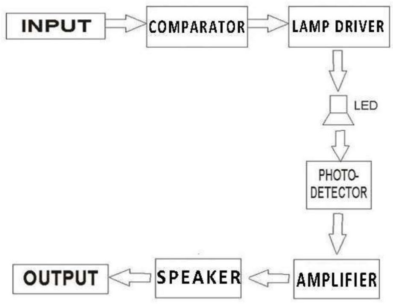


Figure 5 LiFi system for monitoring ship functions

4.2. Underwater LiFi communication

LiFi technology can also be used outside of the ship area to provide ship to ship communication specially in heavy weather conditions. Proposed system will use high power LED emitters submerged in water ensuring that weather conditions have as little as no effect on communication channel. Light signals can travel long distance without any obstruction in water, because of high speed of light which make this ideal for long distance ship communication. Ships equipped which this system can easily and securely communicate without eavesdropping like in radio communication.

Also, light signals can be encrypted using geo- location as key for encrypting. Two vessels should know exact coordinates of each outer (can be obtained using radar or satellite or standard radio communication) so that encryption process could work. Other possible use is for under water oil rigs and communication with autonomous under water systems such as small drones.

In 2013, a firm called 'MARINE COMMS RYUKYU,' which specializes in underwater VLC (UVLC), unveiled a novel equipment that allows a diver to speak with his co-diver at a maximum distance of 30 meters within water at a depth of 30 meters. This is a 2-channel, battery-powered gadget that can last up to 240 minutes.

With lead technology's rapid advancement, expanded use, and quick switching speed, it's suitable for LiFi communication. As a result, the light source in a LiFi system would be a led that would switch on and off in response to changes in the incoming audio signals. A 1 watt power led was used for testing.

The essential thing to remember is that LEDs use relatively little electricity which is economical. An RF power amplifier is required to boost signals flowing into the LiFi transmitter through the 3.5mm audio port. With right voltage signals from RF amplifier can control the LED. However, for a higher-wattage light source, the system needs incorporate a led driver. A light detector is required because the light from the LiFi transmitter must be detected.

Many other types of light detectors may be utilized in a LiFi system with the aid of solar panel which immediately transforms light source to electricity, eliminating the need for a complicated circuit like a light dependant resistor. The solar panel you use must be 4 volts or above in order for it to drive your mobile earbuds if you don't use a preamplifier speaker. In the above-mentioned technology, a decoder is an electric circuit that transforms light into an equivalent electric form capable of reproducing the real audio broadcast by the LiFi transmitter. The decoder circuit is optional in audio transmission via LiFi, such as the proposed system. This system proposes no decoder circuit since the photo detector is a solar panel, which immediately transforms the incoming light to an electric equivalent. To listen to audio at a higher level, a pre-amplified speaker with its own power supply is required.

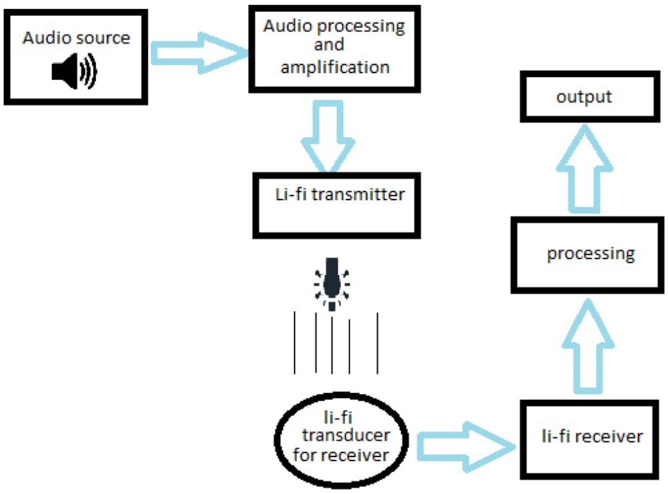


Figure 6 LiFi audio transmission

This light source is aimed towards the LiFi receiver's solar panel. The solar panel detects the variation in the light source and converts it into electric impulses, which are then delivered to speakers. As a result, when there is light audio may be heard through the speakers. When you block a light source with opaque items, the audio will cease since the transmission is obstructed. However, when the audio is obstructed by semi-transparent items, it can be heard on a lesser level, demonstrating that lower intensity light signals may also retrieve data but requiring receiver amplification.

4. CONCLUSION

LiFi and LED are new technologies that will see significant growth and improvement, allowing for the creation of cheaper and better underwater communication solutions employing LiFi. It's a strategy that will soon improve our economy. This technology isn't just for underwater communication it may be used for a number of things.

Without a question, the Internet provides limitless possibilities in terms of accessibility for anyone and everyone, which means openness and, as a result, absolute exposure, which inevitably leads to vulnerability.

A lot of resources was devoted to safeguarding and securing data, which led to invention of many software applications as well as hardware devices aimed to protect valuable information.

With development of LiFi technology this products will have to be altered in a way to conform with new security standards (LiFi relays on physical properties, light can't escape the room like radio waves) to enhance in room communication. As for now LiFi as standalone network is not possible due to many problems described in chapters above. Therefore, use of SDN hybrid LiFi-WiFi networks will remain maybe for decades to come, with improvements in processing rate and buffer size of controller. Recent experiments with these types of networks try to solve queuing and data flow problems in order to provide a stable and fast data rates to end users. Certainly, this type of network will reduce traffic congestion and provide offload to WiFi APs not speaking that it will provide communication to places where RF technology was not able to.

REFERENCES

[1] 5GMF. 5G Mobile Communications Systems for 2020 and Beyond. 5GMF White Paper V1.1, 2017. [Online]. Available: https://5gmf.jp/en/whitepaper/5gmf-white-paper-1-1/

[2] Alresheedi, M. T. Hussein, A. T. and Elmirghani, J. M. H: Uplink design in VLC systems with IR sources and beam steering, IET Commun. 11, 311–317 (2017). [54] R. Bian, I. Tavakkolnia, and H. Haas: 15.73 Gb/s visible light communication with off-the-shelf LEDs, J. Lightwave Technol. 37, 2418–2424 (2019).

[3] Angayarkanni, S. Arthi, R. Nancy, S.: Underwater Communication Using LiFi Technology,Department of Electrical and Electronics Engineering Tejaa Shakthi Institute of Technology for Women

[4] Chandra K. Prasad. R. V. and Niemegeers. I.: An architectural framework for 5G indoor communications, in International Wireless Communications and Mobile Computing Conference (IWCMC) (2015), pp. 1144–1149.

[5] Das. A. K. Ghosh, A. Vibin, A. M.: Underwater communication system for deep sea divers using visible light, Shanthi Prince

[6] Edirisinghe, E. S. S. Karunarathna, P. H. R. S. Dissanayake, D. M. T. B and Godaliyadda, G. M. R. I.: Design and implementation of a bi-directional visible light communication system, IEEE 10th International Conference on Industrial and Information Systems (ICIIS) (2015), pp. 519–524.

[7] Ge, X. Ye, J. Yang, Y. and Li, Q.: User mobility evaluation for 5G small cell networks based on individual mobility model, IEEE J. Sel. Areas Commun., vol. 34, no. 3, pp. 528_541, Mar. 2016. [58] M. B. Rahaim, A. M. Vegni, and T. D. C. Little: A hybrid radio frequency and broadcast visible light communication system, IEEE GLOBECOM Workshops (2011), pp. 792–796.

[8] Haas, H. High-Speed Wireless Networking Using Visible Light. Bellingham, WA, USA: SPIE Newsroom, Apr. 2013.

[9] Haas, H. Yin, L. Wang, Y. and Chen, C.: What is LiFi? J. Lightwave Technol. 34, 1533–1544 (2016).

[10] Kavehrad, M. Chowdhury, M. I. S. and Zhou, Z.: MIMO technology for optical wireless communications using LED arrays and fly-eye receivers, in Short-Range Optical Wireless (Wiley, 2015), pp. 169– 191.

[11] Lipovac, A., Obradović, I. and Zakarija, I.: Ethernet Transport Performance and Triple-Play QoS in Large Ship Environment. NAŠE MORE, 61 (5-6), 124-131 (2014).

[12] Little, T. D. C. and Rahaim, M.: Network topologies for mixed RFVLC HetNets, in IEEE Summer Topicals Meeting Series (SUM) (2015), pp. 163–164.

[13] Zhang, X. Li, R. and Hanzo, L.: Cooperative load balancing in hybrid visible light communications and WiFi, IEEE Trans Commun. 63, 1319–1329 (2015).

[14] Lopez-Perez, D. Ding, M. Claussen, H. and Jafari, A. H.: Towards 1 Gbps/UE in cellular systems: Understanding ultra-dense small cell deployments,'' IEEE Commun. Surveys Tuts., vol. 17, no. 4, pp. 2078_2101, Jun. 2015.

[15] Ma, H. Lampe, L. and Hranilovic, S.: Hybrid visible light and power line communication for indoor multiuser downlink, J. Opt. Commun. Netw. 9, 635–647 (2017).

[16] Pérez-Nicoli, P. Silveira, F. Zhang, X. and Amara, A.: Uplink wireless transmission overview in bi-directional VLC systems, IEEE International Conference on Electronics, Circuits and Systems (ICECS) (2016), pp. 588–591.

[17] Qidan, A. A. Morales-Cespedes, M. and Armada, A. G.: The role of WiFi in LiFi hybrid networks based on blind interference alignment," in IEEE 87th Vehicular Technology Conference (VTC Spring) (2018), pp. 1–5.

[18] Raj, G.P. Prabakaran, P.: Implementation Of LiFi Technology For Underwater Communication Through Light Waves, CK College of Engineering &Technology

[19] Reddy, S. Ashlesh Upadhyaya, V. Anup, M.P: Underwater Wireless Communication System For Large Distance Transmission Immareddy, MVJ Colloege Of Engineering, Computer Science and Engineering

[20] Shao S. Khreishah, A. Rahaim, M. B. Elgala, H. Ayyash, M. Little, T. D. C. and Wu, J.: An indoor hybrid WiFi-VLC Internet access system, IEEE 11th International Conference on Mobile Ad Hoc and Sensor Systems (2014), pp. 569–574.

[21] Wang, Y. Videv, S. and Haas, H.: Dynamic load balancing with handover in hybrid LiFi and WiFi networks, IEEE 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communication (PIMRC) (2014), pp. 548–552.

MACHINE USE OF S-101 CHARTS STORED IN THE DATABASE

Vladimir Brozović
Faculty of Maritime Studies, University of Split
Split, Croatia
E-mail: vladimir.brozovic@pfst.hr

Danko Kezić
Faculty of Maritime Studies, University of Split
Split, Croatia
E-mail: danko.kezic@pfst.hr

Rino Bošnjak
Faculty of Maritime Studies, University of Split
Split, Croatia
E-mail: rino.bosnjak@pfst.hr

UDK 004.658

Summary

In this article it is shown which possibilities are offered for machine inter- pretation of S-101 chart data by storing it into a Postgres database. A good possibility of machine interpretation of the chart data is one of the prerequisites for autonomous navigation. Likewise, it is shown how data from multiple S-101 charts can be used simultaneously with the database structure used. Furthermore, it is shown with examples how to search the curves or points with certain feature codes (examples *Coastline* or *BuoyIsolatedDanger*) in the database. Postgres GIS extensions are briefly explained. Different GIS object types are presented. The difference between geography and geometry types with im- pact on result of used functions is mentioned. The use of some Postgres GIS extension functions is described. Specifically, it is shown with examples how these functions can be used to check if our course could pass over an object or intersect a certain curve from the chart. When checking the possible crossing of a specified point, it is shown how a safety radius can be created around the point for the calculations. This radius can of course depend on various factors. After that, the exact calculation of the current distance to the cal- culated intersection point is also shown. The computational effort required for the execution of the presented GIS functions is estimated. Examples of C code used are also included.

Keywords: S-101 charts, Autonomous ships, Postgres database, GIS exten- sions

1. INTRODUCTION

For the coming era in nautical science, new strategies for the exchange of information between different sources and users are defined. These new strategies are housed in a common set of standards, S-100. The first member of this group, S-101 nautical charts, is the focus of this article. In the authors article for the IMSC 2021 Conference in Bulgaria [1], ideas are presented on how the chart data can be organized into a database so that this data can be used more efficiently by various algorithms used in autonomous vehicles.

This article is practically the continuation of the mentioned article. The paper is organized as follows:

Section 2 gives an overview of the system in which the described chart storage is used. Section 3 very briefly introduces the idea of storing chart data in a database. Section 4 shows with with several examples the usage of charts stored into the database. The first example shows how to find all charts of interest. The second shows how to find all curves with specified feature code (e.g. *Coastline*) in all charts of interest. The third shows how to find all points with specified feature code (e.g. *BuoyIsolatedDanger*) in all charts of interest. The following two examples show all the richness of possibilities gained by saving the chart data into the database and using the PostGIS extensions.

First, it is shown how to calculate the distance to the nearest shore on the existing course. The last example shows how to calculate the distance to the nearest shallow water with a depth less than a given limit on the existing course. Section 5 gives an overview of the C code used for database access and for PostGIS function calls in presented examples. Section 6 estimates the computing power needed for presented examples.

2. SYSTEM DESCRIPTION

This section briefly introduces the system in which the S-101 chart storage into database described later is used.

The system presented in this section is a Collision Avoidance System (CAS). Similar to what other authors of such solutions propose (an example can be found in [2]), the system can, in the event of a collision hazard, generate suggestions for the officer in command as well as direct commands for helm and engines.

The whole system is represented in figure 1.

From various information sources about ship position, speed and course such as AIS data and radar data, the block *collision prediction* calculates with the application of various algorithms the most probable future vessel position.

In calculations of maximum likelihood of future ship position, the electronic chart data and meteorological data are also used. Here arises the first time the need for a more suitable storage of the chart data than provided in the S-101 standard.

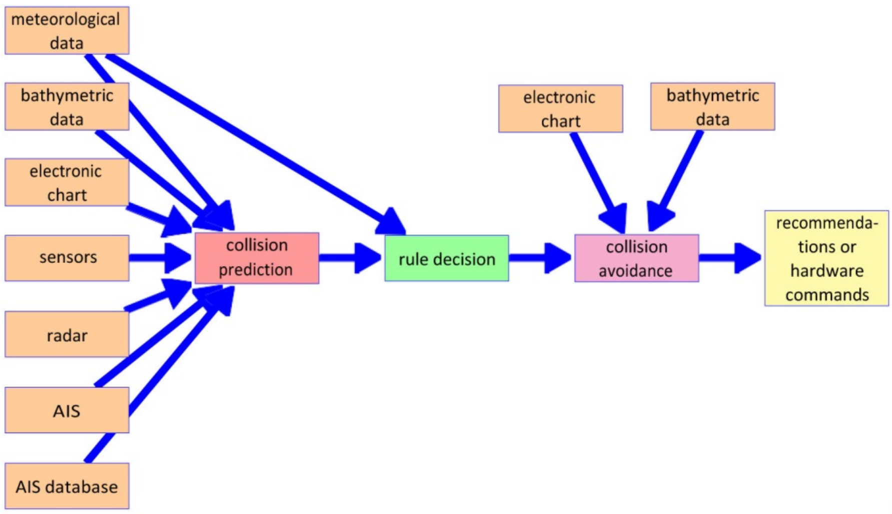


Figure 1 Architecture of accident prevention system

Source: Authors

This calculation is performed every 10 s for all vessels in the considered aquatorium.

At these times the future positions are calculated for the time interval ($t_{now}, t_{now} + 1800s$] , again in 10 s steps.

From calculations of vessel distances for all pairs of vessels and all positions thus predicted, a potential collision hazard is determined. In this way, the information about the ships involved and the potential collision time and collision position is obtained. This information is now passed to block *rule decision*. This block is implemented with a Coloured Petri Net according to rules described in [3].

The block *collision avoidance* checks the course change recommended by the block *rule decision* with the basic conditions from nautical charts and bathymetric data. Here one meets again the need for a more suitable storage of the chart data. In accordance with all this information, the mentioned block gives a recommendation of the course change to the officer or, in case of unmanned navigation, directly to the helm and engines.

3. STORING THE CHART DATA INTO THE DATABASE

A short overview of the S-100 standard group is given in articles [4]. Detailed information about the members of the S-100 standard group can be found in [5]. The specification of the data format for electronic nautical charts is given in [6]. The description of the contents of the electronic nautical charts can be found in [7].

A slightly better insight into the ISO8211 format and records of the chart data can be found in the author's article [1]. In the referenced article it is also described in detail how the storage of the map database into the database was realized in the current project.

PostgreSQL was chosen for the project. The following properties speak in favor of choosing this database software:

- Free use
- Virtually unlimited database sizes
- Good support for synchronous (blocked) and asynchronous (unblocked) access from C programs
- Search process planner that can be controlled via parameters. For example, the search from younger to older entries can be carried out in this order and without sorting.
- The number of coworkers in the search processes can be easily adapted to the hardware architecture (number of CPUs available)

The design of the database tables and the indexing of the fields in these tables play a very important role for the optimal usability of the data from the database in real time. For the design of real-time applications, which are based on relatively large database tables, good knowledge of the planning strategies when executing a search command in the database software used must also be available. This good knowledge of these strategies as well as of possible influences of these strategies often enable a massive reduction of the search times (often several hundred times).

3.1. PostGIS extension

In addition to the database features listed above, using the Postgres database opens the possibility of using a powerful tool, which is the PostGIS extension of the Postgres software. Once installed, a variety of functions can be used in queries for gemetric (plane) and geographic (spheroid according to WGS-84) calculations.

Examples of such functions used in Authors application are *ST_Azymuth*, *ST_Distance*, *ST_Intersection*, *ST_Intersects* etc.

3.2. PostGIS data types

The basic data types in PostGIS are point, line and polygon.

All data types have two possible spatial options: *geography* and *geometry*. If arguments of a function (e.g. *ST_Distance*) are specified to have spatial option *geometry*, then the result of the function will be calculated in Cartesian coordinate system. Otherwise, if arguments of the function have spatial option *geography*, then the coordinates are considered as points on the spheroid and the calculations are performed on the spheroid.

4. EXAMPLES OF NAUTICAL TASKS AND THEIR SOLUTIONS WITH PRESENTED APPROACH

4.1. Example 1: Finding charts of interest

Provided that the current ship position is given with: (16.1478, 43.40875) and vessel speed is 20 kn, the area of interest is the circle around this point with a radius of 10 nautical miles. This radius is arbitrarily set to a distance that can be reached in half an hour at current speed.

Well, in the database we have to find the charts where the respective chart area contains a part of the circle defined above.

Chart index and chart area for each chart in the database are found with the SELECT statement:

*SELECT * from chart_range;*

The result is shown in figure 2

```
vlado: psql -h localhost -p 25432 -U docker s101_db
s101_db=# SELECT * from chart_range;
 chart_id |   chart_name   | longitude_west_bound | longitude_east_bound | latitude_south_bound | latitude_north_bound | date_stamp
----------+----------------+----------------------+----------------------+----------------------+----------------------+------------
       42 | 101HR003C0021 |            15.286961 |            16.461844 |            43.286703 |            43.863339 | 2020-01-26
       44 | 101HR0050047E |            16.293611 |            16.496667 |            43.455556 |            43.556944 | 2020-01-26
       45 | 101HR0060047B |            16.462108 |            16.474328 |            43.526711 |             43.53185 | 2020-01-26
       46 | 101HR0060047C |            16.452942 |            16.470439 |            43.534489 |            43.539211 | 2020-01-26
       47 | 101HR0060047F |            16.426861 |            16.444361 |            43.499472 |            43.508361 | 2020-01-26
       50 | 101HR003C0026 |            16.299167 |            17.453333 |            42.958333 |            43.533333 | 2020-01-27
(6 rows)

s101_db=#
```

Figure 2SELECT from Table *chart_range*

Source: Authors

Now the following query must be made for each result line from figure 2:

SELECT ST_Intersects(ST_Buffer(ST_MakePoint(ship longitude, ship latitude)::geography, radius of interest in m), ST_MakePolygon('LINESTRING(longitude_west_bound latitude_south_bound, longitude_west_bound latitude_north_bound, longitude_east_bound latitude_north_bound, longitude_east_bound latitude_south_bound, longitude_west_bound latitude_south_bound)')::geography);

This query for the first result line from figure 2 and its result are shown in figure 3.

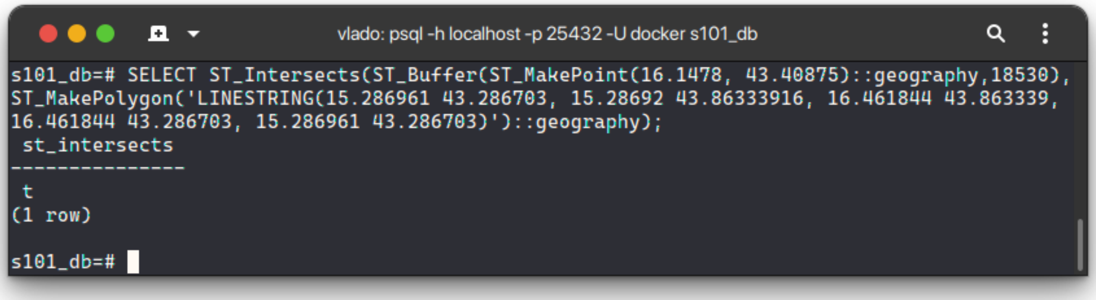


Figure 3 Checking whether the chart is of interest

Source: Authors

The function *ST_MakePoint(long, lat)::geography* makes a point with coordinates *(long,lat)* in the WGS-84 coordinate system. The function *ST_MakePolygon('LINESTRING(long1 lat1, long2 lat2, long3 lat3, long4 lat4, long1 lat1)')::geography* makes a polygon with vertices *(long1,lat1), (long2,lat2), (long3,lat3), (long4,lat4)* in the WGS-84 coordinate system. The function *ST_Buffer(Point p, Radius r)* makes a circle with radius r in meters around point p and the function *ST_Intersects(Object 1, Object2)* checks if the parts of the two objects overlap. Result of this check is either *t* (true) or *f* (false). True means that a part of our circle of interest is in the checked chart.

At this time, the difference between PostGIS functions *ST_Intersection* and *ST_Intersects* should be briefly explained. The *ST_Intersection* function gives the geometry that results with the intersection of the two function arguments. The *ST_Intersects* function specifies whether the faces of the two objects partially overlap. A good example for this distinction are two circles with the same center and different radii. So in this case the function *ST_Intersection* gives an empty line as answer, i.e. no geometry arises as intersection of the two circles and the function *ST_Intersects* gives as answer *t* (true) because the area of the smaller circle is a part of the area of the larger circle.

4.2. Example 2: Searching for curves with certain feature codes

In this example it is shown how to find in the database in the electronic charts of interest all the curves with the feature code *Coastline*. For each chart_id found in the subsection 4.1, the record with the ftcd value equal to 'Coastline' is searched in the ftcs table. From this record, only the value ftnc will be used in next steps.

Assuming that the chart_ids 42, 44 and 50 were found in the subsection 4.1, this is done with the following SELECT commands:

SELECT ftnc FROM ftcs WHERE chart_id=42 and ftcd='Coastline';

SELECT ftnc FROM ftcs WHERE chart_id=44 and ftcd='Coastline'; SELECT ftnc FROM ftcs WHERE chart_id=50 and ftcd='Coastline';

For all charts (42, 44 and 50), the ftnc value is 64. This is not necessarily always the case.

The following command will then find all records in the frid table that have chart_id 42 and ftnc value 64 (all frid records that belong to a 'coast line'):

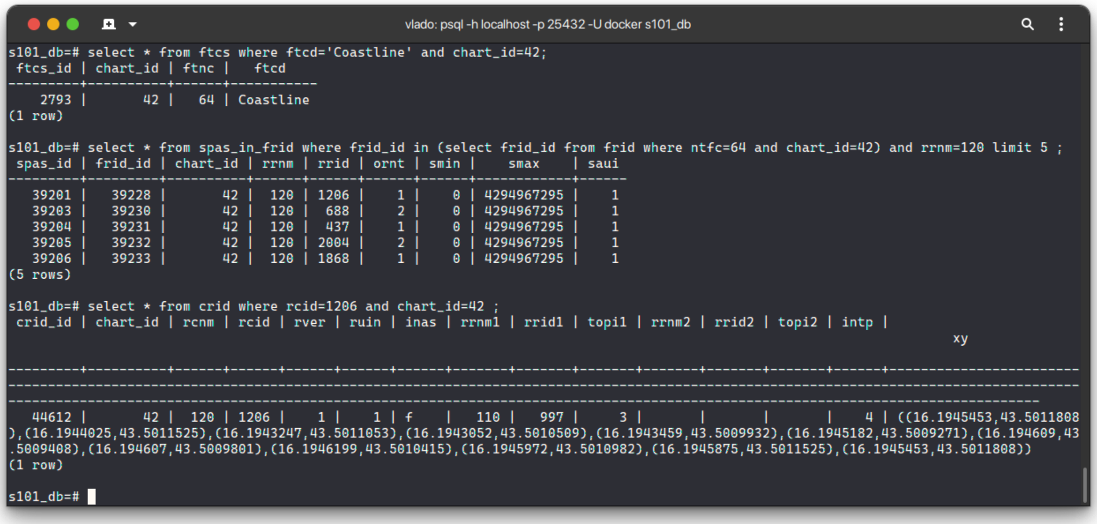
*SELECT * from frid where chart_id=42 AND ftnc=64;*

For every value *iiii* for frid_id in the result from the last select, the following is done: *SELECT * from spas_in_frid where chart_id=42 AND frid_id=iiii AND rrnm=120;* and from this result rrid is read.

Now for all rrid results *jjjj* the next SELECT in the table crid is done:

*SELECT * from crid where chart_id=42 AND rcid=<rrid value* jjjj *from last result>;*

Each answer is one coastline on the chart with chart_id equal to 42. An example of such a search is shown in figure 4.



```
s101_db=# select * from ftcs where ftcd='Coastline' and chart_id=42;
 ftcs_id | chart_id | ftnc |   ftcd
---------+----------+------+-----------
    2793 |       42 |   64 | Coastline
(1 row)

s101_db=# select * from spas_in_frid where frid_id in (select frid_id from frid where ntfc=64 and chart_id=42) and rrnm=120 limit 5 ;
 spas_id | frid_id | chart_id | rrnm | rrid | ornt | smin |    smax    | saui
---------+---------+----------+------+------+------+------+------------+------
   39201 |   39228 |       42 |  120 | 1206 |    1 |    0 | 4294967295 |    1
   39203 |   39230 |       42 |  120 |  688 |    2 |    0 | 4294967295 |    1
   39204 |   39231 |       42 |  120 |  437 |    1 |    0 | 4294967295 |    1
   39205 |   39232 |       42 |  120 | 2004 |    2 |    0 | 4294967295 |    1
   39206 |   39233 |       42 |  120 | 1868 |    1 |    0 | 4294967295 |    1
(5 rows)

s101_db=# select * from crid where rcid=1206 and chart_id=42 ;
 crid_id | chart_id | rcnm | rcid | rver | ruin | inas | rrnm1 | rrid1 | topi1 | rrnm2 | rrid2 | topi2 | intp |
                                                                                                               xy

   44612 |       42 |  120 | 1206 |    1 |    1 | f    |   110 |   997 |     3 |       |       |       |    4 | ((16.1945453,43.5011808
),(16.1944025,43.5011525),(16.1943247,43.5011053),(16.1943052,43.5010509),(16.1943459,43.5009932),(16.1945182,43.5009271),(16.194609,43
.5009408),(16.194607,43.5009801),(16.1946199,43.5010415),(16.1945972,43.5010982),(16.1945875,43.5011525),(16.1945453,43.5011808))
(1 row)

s101_db=#
```

Figure 4 Search for the *Coastline* curves in the database

Source: Authors

4.3. Example 3: Searching points with certain feature codes

This example shows how a sequence of Postgres and Postgres GIS queries can be used to check if a specified route is getting close to a dangerous point in the circle of interest. Dangerous points are searched in all charts of interest. To find the charts of interest the procedure from 4.1 is used. To keep the examples simple here, only the dangerous points with the attribute *BuoyIsolatedDanger* are searched. Assuming that the chart_id's 42, 44 and 50 were found in previous step, this is done with the following SELECT commands:

SELECT ftnc FROM ftcs WHERE chart_id=42 and ftcd='BuoyIsolatedDanger'; SELECT ftnc FROM ftcs WHERE chart_id=44 and ftcd='BuoyIsolatedDanger'; SELECT ftnc FROM ftcs WHERE chart_id=50 and ftcd='BuoyIsolatedDanger';

For all charts (42, 44 and 50), the ftnc value is 51. This is not necessarily always the case.

The following command will then find all records in the frid table that have chart_id 42 and ftnc value 51 (all frid records that belong to a 'BuoyIsolatedDanger'):

*SELECT * from frid where chart_id=42 AND ftnc=51;*

It will be shown at this time how the Postgres gives the possibility to nest several commands with the construction IN in a single SELECT command. Example of such a nesting, which finds all dangerous points with type *BuoyIsolatedDanger* from the map with chart_id=42, is shown in figure 5 on page 9.

```
vlado: psql -h localhost -p 25432 -U docker s101_db
s101_db=# select * from prid where chart_id=42 and rcid IN ( select rrid from spas_in_frid
where frid_id IN (select frid_id from frid where ntfc IN ( select ftnc from ftcs where ftcd
='BuoyIsolatedDanger' and chart_id=42) and chart_id=42));
 prid_id | chart_id | rcnm | rcid | rver | ruin |           yx            | xyz
---------+----------+------+------+------+------+-------------------------+-----
  109781 |       42 |  110 | 2459 |    1 |    1 | (16.4565406,43.5342385) |
  110797 |       42 |  110 | 3475 |    1 |    1 | (15.9113771,43.5286986) |
  110865 |       42 |  110 | 3543 |    1 |    1 | (16.1478,43.40875)      |
  110866 |       42 |  110 | 3544 |    1 |    1 | (16.1912667,43.4319)    |
(4 rows)

s101_db=#
```

Figure 5 Example how to find all dangerous points of specified type with a single com- mand

Source: Authors

For each dangerous point found in this way, a check can be made to see if the line between the current position point and the future position point comes to close this point. This check is done by using the GIS function *ST_Intersection*. The reader will notice here the mentioned difference to the function *ST_Intersects* used earlier.

A safety radius around the dangerous points is defined at first. This can be depending on the width of the ship. The assumed safety radius for a ship width of 25m in this example is 100m.

In figure 6 on page 9, an example is shown where the course from the point (16.12751, 43.3788761) to the point (16.1593535,43.42376) comes too close to a dangerous point (16.1475, 43.40875).

```
vlado: psql -h localhost -p 25432 -U docker s101_db
s101_db=# SELECT ST_AsText(ST_Intersection(ST_Buffer(ST_MakePoint(16.1478, 43.40875)::geography,100),
'LINESTRING(16.12751 43.3788761, 16.1593535 43.42376)'::geography));
                                 st_astext
-----------------------------------------------------------------------------------------------
 LINESTRING(16.148078113109932 43.407875945512416,16.148941054764457 43.40909194324895)
(1 row)

s101_db=#
```

Figure 6 Example when the course to second point comes too close to a dangerous point

Source: Authors

Between the points (16.14807811...,43.40787...) and (16.148941...,43.409091...) the course comes closer than 100 m to the dangerous point.

How to calculate the next point from actual point, azimuth and distance to the next point with PostGIS will be shown in the next example.

4.4. Example 4: Distance to the nearest shore on the current course

At first, in all charts of interest, found as described in subsection 4.1, all curves with feature code *Coastline* are found, as described in subsection 4.2.

At this point the next powerful PostGIS function is introduced. This is the *ST_Project* function, which calculates the second point on the WGS-84 sphereoid from the given point, azimuth and distance from the given point.

If the ship at point (16.1478, 43.40875) has course 33.885°, then the future point on earlier presented 10 nautical miles circle is calculated with the following PostGIS Query:

SELECT ST_AsText(ST_Project(ST_MakePoint(16.1478, 43.40875)::geography, 18530, radians(33.885)));

Now the PostGIS function *ST_Intersection* is used to find a possible intersection between the line from the current point to the future point with each coastline found in previous steps. If no intersection exists the answer of the query is an empty line. For each intersection found (and this is always a point) the distance to this point is calculated with the function *ST_Distance*. A minimum over all distances calculated in this way is the distance to the nearest shore on the course.

Example in figure 7 shows the whole procedure for the coastline of a small island with the rcid=1187 in the chart with the chart_id=42. With the assumed course 33.885° the ship would run into the island in the point with coordinates (16.17794838, 43.441457) and up to this point the distance is 4377.73 m.

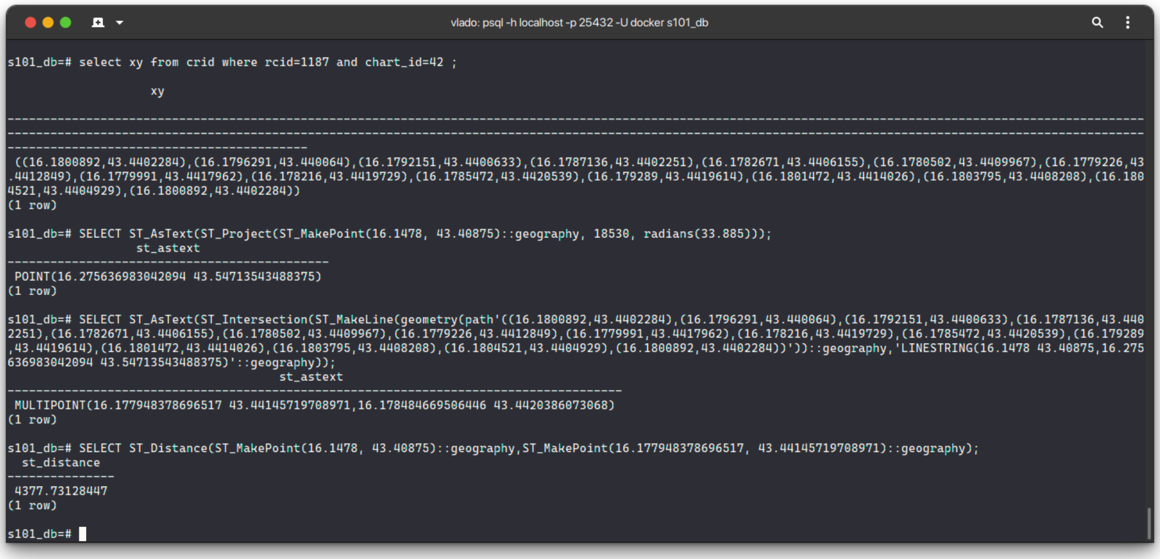


Figure 7 Distance to nearest shore

Source: Authors

4.5. Example 5: Distance to the nearest shallow water with depth less than 4m on the current course

The information about the sea depth is given in S-101 chart in Multipoint Records. The following procedure based on the previous examples for solving this task would be possible:

1. Find all charts of interest according to 4.1.
2. For the charts found, all multipoint records are read from the table mrid in the database.
3. For each point of each record, the following checks are performed in this order:
   a) the depth is less than 4m
   b) the point is inside the circle of interest
4. A circle with a radius *r* is placed around each point that meets previous criteria. Its value depends on the size of the ship and the distance to the neighboring points from the record (sum of all values).
5. For each of these circles, the PostGIS function *ST_Intersection* is used to find a possible intersection with the line on which our direction lies.
6. If an intersection exists, the distance to this intersection is calculated with PostGIS function *ST_Distance*.
7. The smallest in this way calculated distance is the result.

The complete solution of this task would go beyond the scope of this article.

5. C CODEEXAMPLE

In order to use Postgres with PostGIS functions from the C program, only a small set (6) of Postgres interface functions are used. These are:

*(PGconn *) PQconnectdb((char *) database)*
*(PGresult *) PQexec((PGconn *) conn , (char *) pg_command_string) (int) PQntuples((PGresult *) result)*
*(int) PQfnumber((PGresult *)result, (char *) fieldname)) (char *) PQgetvalue((PGresult *) result, 0, (int) fieldnumber) (int) PQclear((PGresult*)result)*

An example of using these interface functions in C is given in figure 8.

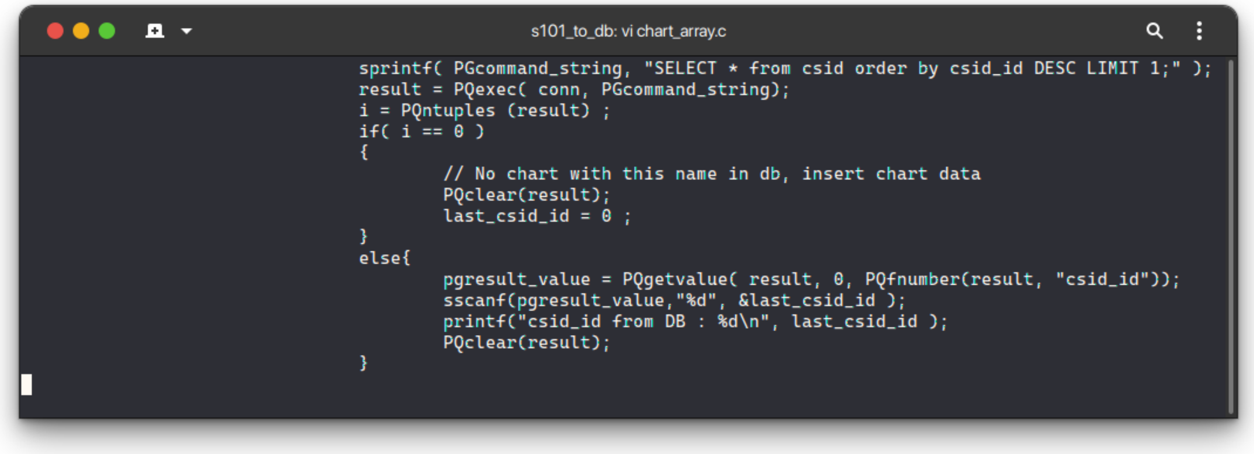


Figure 8 Postgres C Interface

Source: Authors

6. ESTIMATED COMPUTING POWER

The target platform developed for the project, from which very small parts have been presented in this paper, allows a very large set of previously described checks in real time. This platform is at the upper edge of today's technological possibilities for embedded systems and is characterized by:

The LX2160A processor has sixteen 32-bit/64-bit Arm®Cortex®-v8 A72 CPUs, running at 2.2GHz.

This Processor has 24 SerDes / PCIe 4.0 lines running up to 25GHz. The processor power consumption with $\approx 27W$ is moderate. 128 bit wide DDR4 interface with 3.2 GTransfers/s => 51.2 GByte/s

Two M2 Key M slots with 4 serdes/PCIe 4.0 lines each are provided for NVME flash devices.

The fastest and most modern NVME cards for M.2 slots with four PCIe 4.0 lines have capacities up to 1TByte and random read and write data transfer rate up to 1000000 x (4kbyte blocks)/s each. Two storage device in two M.2 slots are used for database data and usage of two devices enables very fast searches even in very large databases.

7. CONCLUSIONS

The new standard group S-100 describes powerful possibilities for coding of several types of data used in navigation. The first of the group, named S-101, describes the electronic charts. In the Authors application, the data from the S-101 electronic charts are used very intensively.

It was tried here to explain to the reader what are the advantages of storing the S-101 chart data into the database in the way suggested by the authors in earlier articles [1]. Storage of this data in a relational database allows searching the data according to many criteria. The authors were guided in the design of the database and powerful search capabilities resulting from this design by needs arising in the development of various algorithms for autonomous vessels. Furthermore, these search capabilities combined with information about the ship's current position, speed and course could generate information on an additional display that would help the officer in manned navigation to make some important decisions in a shorter time.

With the help of such techniques, it would be relatively easy to prevent shipping accidents such as those involving the *Marco Polo* ferry.

REFERENCES

[1] V. Brozović, R. Bošnjak, D. Kezić, and F. Bojić, "Storing S-101 chart data into a common database," in *Proceedings of IMSC 2021*, (Varna, Bulgaria), NVNA, Sep. 2021.

[2] Y. Huang, L. Chen, R. R. Negenborn, and P. va Gelder, "A ship collision avoidance system for human-machine cooperating during collision avoidance," *Ocean Engi- neering*, vol. 217, 1 December 2020.

[3] D. Jašić, G. Belamarić, and A. Gundić, *Međunarodna pravila o izbjegavanju su-dara na moru = International regulations for preventing collisions at sea*. Zadar: Sveučilište u Zadru, Pomorski odjel, 2011, isbn: 978-953-331-000-8.

[4] R. Bošnjak, D. Kezić, and V. Brozović, "Overview of S-100 group of standards for use in nautical navigation," in *Proceedings of ICTS 2020*, (Portorož, Slovenia), Faculty of Maritime Studies and Transport, Sep. 2020, pp. 54–60, isbn: 978-961-7041-08-8.

[5] I. H. ORGANIZATION. (2020). S-100 specification numbers, [Online]. Available: http://s100.iho.int/S100/home/s-100-specification-numbers (visited on 05/01/2020).

[6] I. S. ISO/IEC, *Iso/iec 8211 information technology - specification for a data de- scriptive file for information interchange*, Second edition, Reviewed and confirmed in 2000, IEC, Oct. 1994.

[7] I. H. ORGANIZATION, *Iho electronic navigational chart product specification*, 1.0.0, IHO Publication S-101, 4b quai Antoine 1er, Principauté de Monaco: International Hydrographic Organization, Dec. 2018.

THE PHENOMENON OF KNOCKING COMBUSTION AND THE IMPACT ON THE FUEL EXCHANGE AND THE OUTPUT PARAMETERS OF THE DIESEL ENGINE OPERATING IN THE DUAL-FUEL MODE (DIESEL-CNG)[1]

Janusz Chojnowski
Institution: Military University of Technology in Warsaw
Warsaw, Poland
E-mail: janusz.chojnowski@wat.edu.pl

Mirosław Karczewski
Institution: Military University of Technology in Warsaw
Warsaw, Poland
E-mail: miroslaw.karczewski@wat.edu.pl

Grzegorz Szamrej
Institution: Military University of Technology in Warsaw
Warsaw, Poland
E-mail: grzegorz.szamrej@wat.edu.pl

UDK 629.5:621.43
662.7

Summary

The performance of dual fuel engines may be limited by the phenomenon of knocking combustion. Avoiding the phenomenon of knock in a diesel engine using its positive attributes, such as high compression ratio, may be difficult to achieve in engines converted to dual-fuel operation. This study presents research of handling with this problem and the result on the obtained percentage of fuel gas exchange as well as the impact on the engine performance in the inlet of a turbocharged six-cylinder inline unit.

Keywords: dual-fuel, fuel exchange, fuel replacement, CNG, knock

1. INTRODUCTION

The phenomenon of uncontrolled combustion, common in spark ignition engines, knocking, is linked with a high rate of energy release, a rapid build-up of pressure and, excessive heat transfer. In order to obtain correct and effective engine operation, this phenomenon must be avoided. In order to avoid knocking, there are many different solutions related to the control of the engine, also included in the process of its design. In the case of the dual-fuel system, the degree of replacement of diesel with gas fuel may increase the risk of knocking. The presented studies show responses to tune in the context of knocking in an experimental sequential gas injection system implemented just pre-inlet valve, which are characterized by a much greater replacement factor than the old injection systems available on the market before the turbine or injection into the intake manifold, but without emulating diesel injectors (Fig. 1).

[1] The publication was created as a result of work under: Poland Republic, National Centre for Research and Development, Military University Technology; Name of the competition: Ścieżka dla Mazowsza; Agreement No. MAZOWSZE / 0123 / 19-00; Subject: "Innovative ecological CNG installation for diesel engines limiting the emission of harmful exhaust components together with a mobile diagnostic platform."

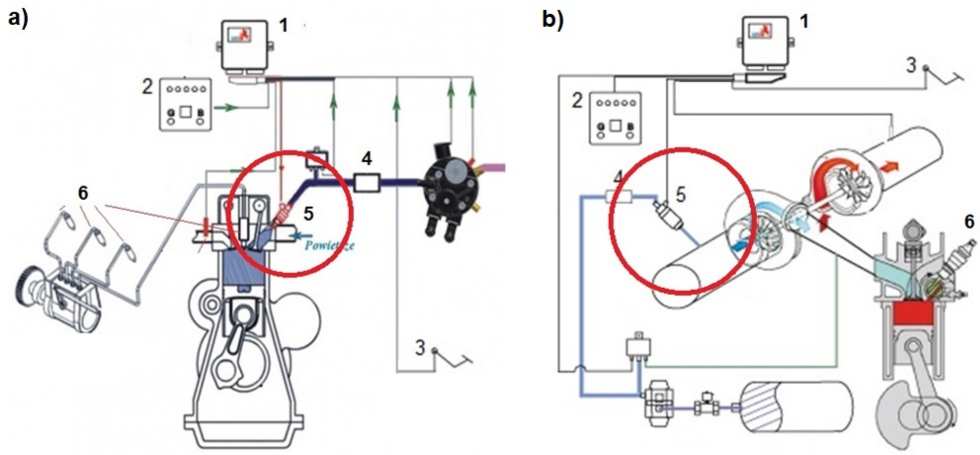


Figure 1 Comparison of dual fuel systems: a) sequential gas injection pre- intake valve, b) pre-turbocharger gas injection: 1 – ECU, 2 – switch, 3 – acceleration pedal, 4 – gas filter, 5 – gas injector, 6 – diesel injector

Source: [16, 17]

1.1. The knock phenomenon

The knock phenomenon is caused by uncontrolled rapid combustion energy release. This is due to the uneasy flame propagation due to the self-ignition of part of the unburned air-fuel mixture as its shown in figure 2 [1]. This phenomenon is the result of a complex interaction between turbulent flame propagation processes and pre-ignition-oxidation reactions of part of the gas at the end of the flame in the mixture that is still consumed by the flame [3].

Knocks affect the life of the engine by impeding lubrication and increased susceptibility to overheating and mechanical damage. In order to avoid knocking, motors are usually designed conservatively, without the motor reaching the best possible performance [10].

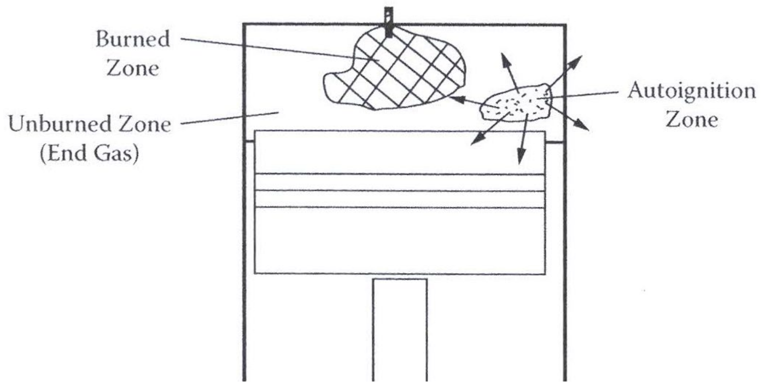


Figure 2 Knocking phenomenon in a SI engine with indirect gas injection

Source: [4]

The knocking process can be detected by:

- monitoring specific engine vibrations,
- monitoring of the specific noise emitted by the engine,
- unusual increases in cylinder pressure (pressure pulsation effect),
- drop in performance,
- negative change in exhaust gas composition and temperature.

The knock intensity is directly related to the rate of pressure increase in the cylinder. Then this is a function of the net energy released by self-ignition, which mainly controls the intensity of the cylinder pressure change over time. Proven solutions of knock sensors using strain gauges or pressure sensors placed in the cylinder are available on the market, but they have their limitations. [1, 3, 15].

It can be seen from figure below (Fig. 3) that knocking occurs with CH_4 for high compression ratios [2]. The figure shows a typical representation of the area of the knocking mixture relative to the normal limits of the working mixture with variations in the compression ratio for a SI engine running on CH_4.

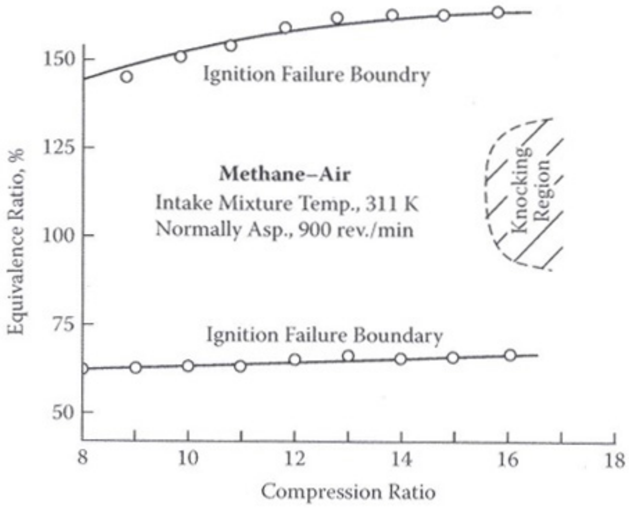


Figure 3 The quality of the methane-air mixture on its ignition ability (SI engine)

Source: [2]

Self-ignition of a homogeneous mixture of methane (without an external ignition source) is also possible if a sufficiently high inlet temperature or a high compression ratio is applied (Fig. 4).

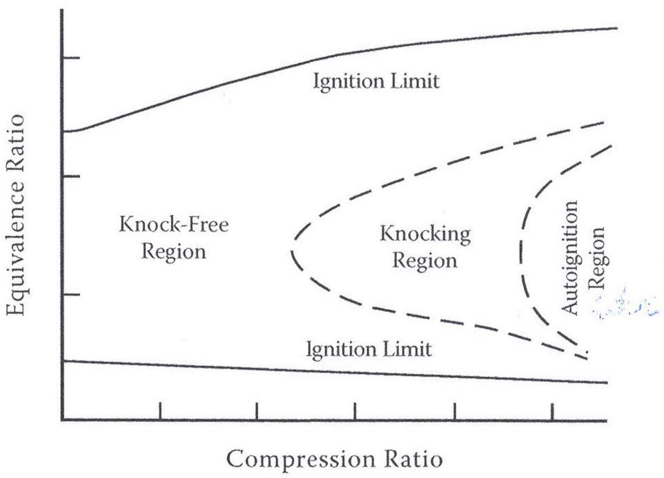


Figure 4 Representation of knock and compression-ignition an ignition limits with compression ratio for methane-powered engine

Source: [3]

1.2. Diesel engine knock

The characteristic knocking noise can also be found in a compression-ignition engine, depending on the intensity of the pressure build-up after self-ignition. This effect appears noticeably after long ignition delays or at low inlet temperatures as shown in Figure 5. Operating in this condition results in increased shocks being transferred to further engine operating parts. This effect can be called diesel knock [4, 14].

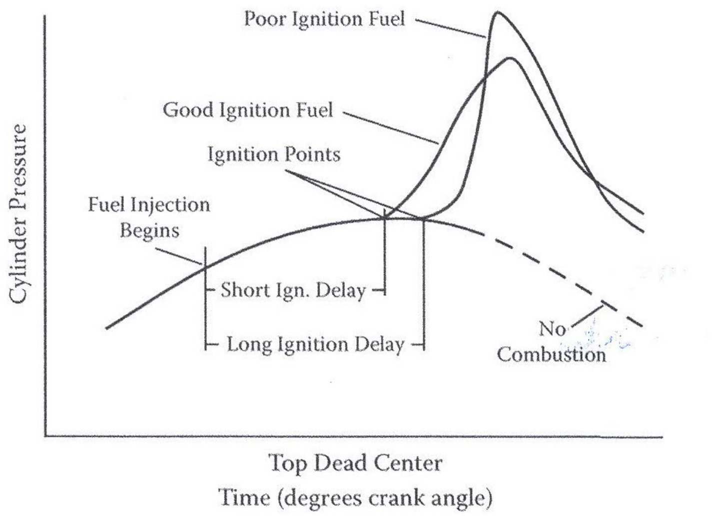


Figure 5 Pressure build-up diagram for two fuels with different ignition delay in CI engines

Source: [4]

Unlike spark-ignition or dual-fuel engines, where knocking combustion is associated with the final stages of combustion, in a diesel engine it is associated with the initial combustion phase. The factors determining the knocking in a CI engine are [1].:

- engine design,
- injection type (direct or indirect),
- ignition method,
- ignition delay.
- compression ratio,
- engine size,
- engine speed,
- internal combustion chamber temperature,
- engine wear level

Reducing the knock intensity in a CI engine consists in changing (reducing) ignition delay. It is also effective to reduce the amount of fuel stored in the combustion chamber during ignition delay, but modern common rail systems solve this problem well [3, 5].

1.3. Dual-fuel engine knock

The release of combustion energy in a dual-fuel engine is related to the sum of the energy of the pilot fuel (diesel) and gas fuel (CNG in our tested engine). A pilot dose after ignition spreads the flame and initiates turbulent combustion of most of the remaining gas charge. This combustion mode is responsible for the ability of dual fuel engines to benefit from the combustion of air-fuel mixtures that are much leaner than those normally possible in SI gas engines. This contributes to the high efficiency of dual-fuel engines. [1, 3, 12].

In a dual-fuel engine, immediately after the injection of the combustion initiation fuel and a short delay, ignition takes place and combustion begins very quickly and practically simultaneously at many points of the gas charge. The turbulent flames then begin to spread from these ignition centers to local areas of the gas/air mixture. Such an ignition mode, despite the high compression ratios used in dual-fuel engines, reduces the likelihood of self-ignition of the mixture compared to SI [13]. Under certain circumstances, when large pilot doses are used and, at the same time, during their ignition, the areas of the gas-air mixture ignite together, an effect similar to diesel knocking can be obtained. [3].

The gas-air mixture should have adequate resistance to spontaneous combustion and should be introduced into the cylinder at such a time that it does not have enough time for self-ignition before, during or after the rapid release of energy from the pilot fuel into its immediate vicinity. Failure to do so may lead to intense knocking, which results in too rapid pressure increase, overheating of the engine (which negatively affects its performance) and ultimately to mechanical damage, as shown in fig. 6. [13].

Figure 6 Damaged engine liner and piston due to dual fuel knocking

Source: [13]

Figure 7 shows a schematic record of the cylinder pressure in a dual-fuel engine running on CH_4 with and without knocking. Figure 8 shows the size of the pilot dose during the operation of a dual-fuel methane diesel engine in the context of a rapid increase in pressure leading to a knock

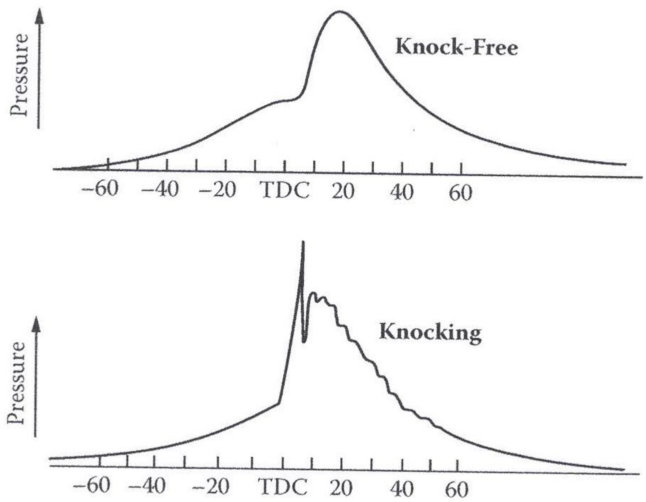


Figure 7 Cylinder pressure in a dual-fuel engine running on CH_4 with and without knocking combustion

Source: [3, 5]

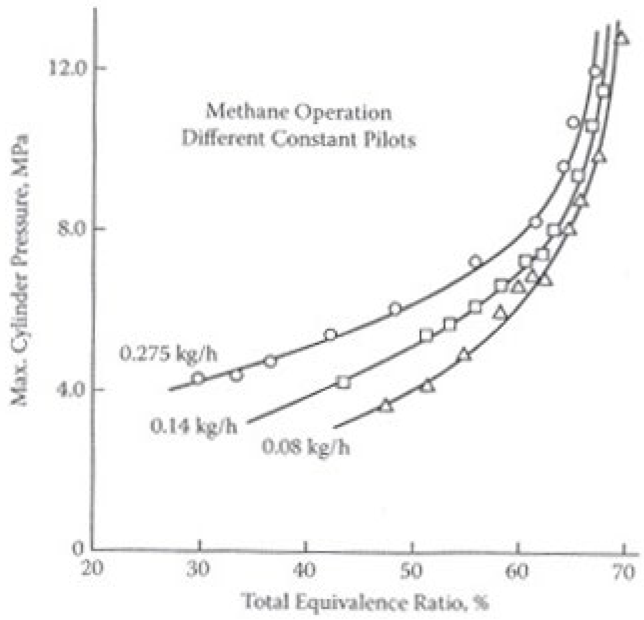


Figure 8 Three different amounts of pilot doses in the context of the variability of the maximum pressure value and total equivalence ratio (diesel-CNG engine)

Source: [3, 7]

The knocks found in engines operating on dual-fuel mode can be caused by both types: diesel or gas knockings. A large amount of lean premixed fuel-air which can be considered as an end gas relation to the regions of pilot self-ignition, may be subject to rapid autoignition reactions assisted with high temperature afeter pilot ignition, leading to end fuel type knocking [3]. Too small pilot doses may lead to turbulent combustion of the gas-air mixture, which may, under specific conditions (e.g. high temperature), lead to knocking combustion similar to that of SI.

When it comes to knocking, the temperature of the mix has a paramount importance. The effects of changes in the fuel-air ratio are relatively less severe and primarily regulate the resulting combustion temperature as shown in Figure 9, it shows changes in the graph of the heat release rate from a dual-fuel engine with increasing fuel gas concentration at the inlet, causing knocking at a constant pilot size.

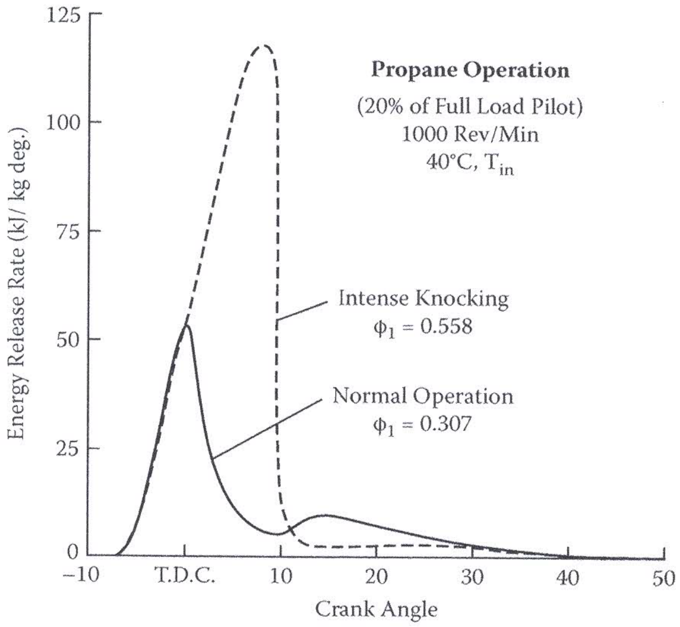


Figure 9 The course of energy release in a function of crankshaft rotation for two different gas-air mixtures at a constant pilot dose.

Source: [3, 6]

With the reciprocal of the absolute intake manifold temperature for a dual fuel type engine, the output power for different fuels and pilot settings appears to decrease logarithmically (limited by knocking) as shown in Figure 10 [3].

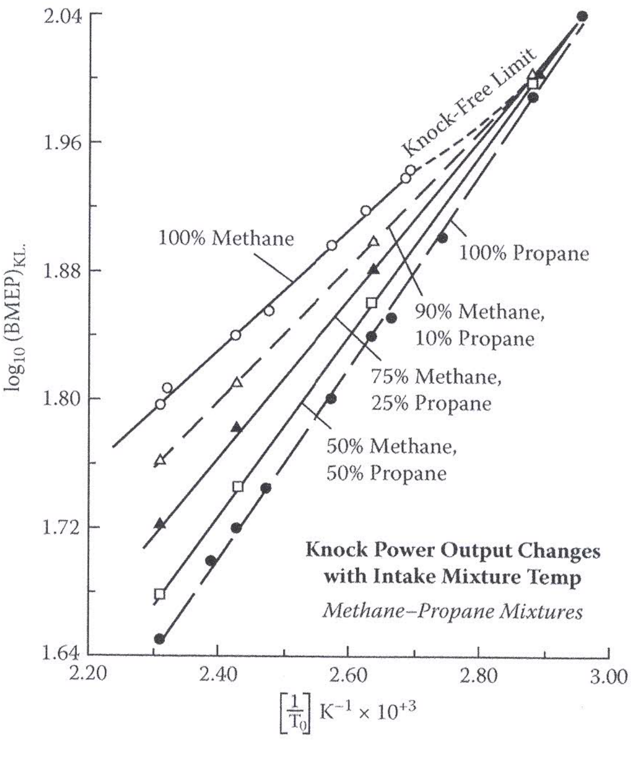


Figure 10 Log BMEP with the reciprocal of the absolute temperature of the inlet mixture for various methane-propane mixtures (constant pilot, constant RPM, reduction of knocking combustion)

Source: [3, 5]

Methane is more tolerant to temperature increase in inlet mixture than other gas fuels. The action on LPG also shows that the log-limited output of power is linearly related to the reciprocal of the absolute temperature of the inlet mixture. Increasing a pilot size causes the knocking to start faster with a corresponding reduction in knockless power [1, 3, 11, 14]

2. METHODOLOGY

The aim of the research was to tune the Volvo D13C engine configuration to work on dual-fuel diesel-CNG mode. The goal was to maintain similar (or better) torque values in the dual-fuel cycle compared to the nominal values on diesel fuel operating mode with the focus of possible the greatest replacement of the base fuel (diesel) to gaseous fuel (CNG) till the points reaching the knock limit. In the tested case, the engine was converted to dual-fuel operation by adding a prototype sequential indirect gas injection system. The tests were carried out on an engine dynamometer. Figure 11 shows the operation scheme of the tested engine and the principles of the research setup.

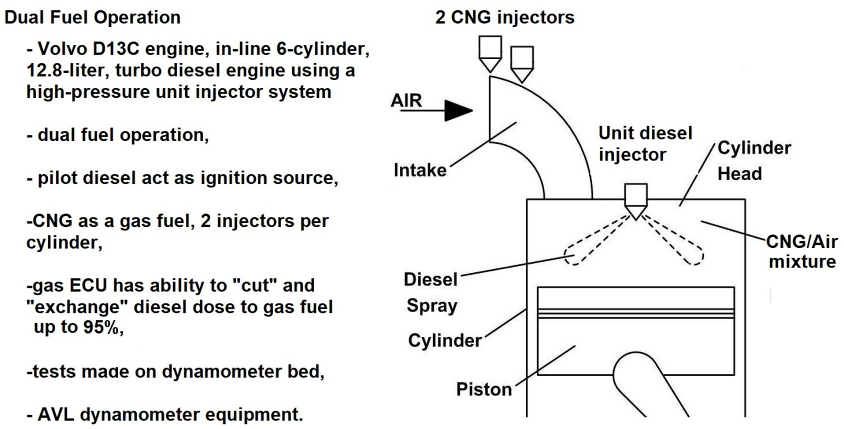


Figure 11 Schematic of the tested engine operation and principles of the research setup.

Source: Authors' archive

3. RESULTS

3.1. Fuel replacement

Figure 12 shows a screenshot from the gas controller software showing the percentage of replacement of the diesel fuel to CNG with the area of knocking combustion marked. Below the red line, the replacement percentage is set as close to knock as possible.

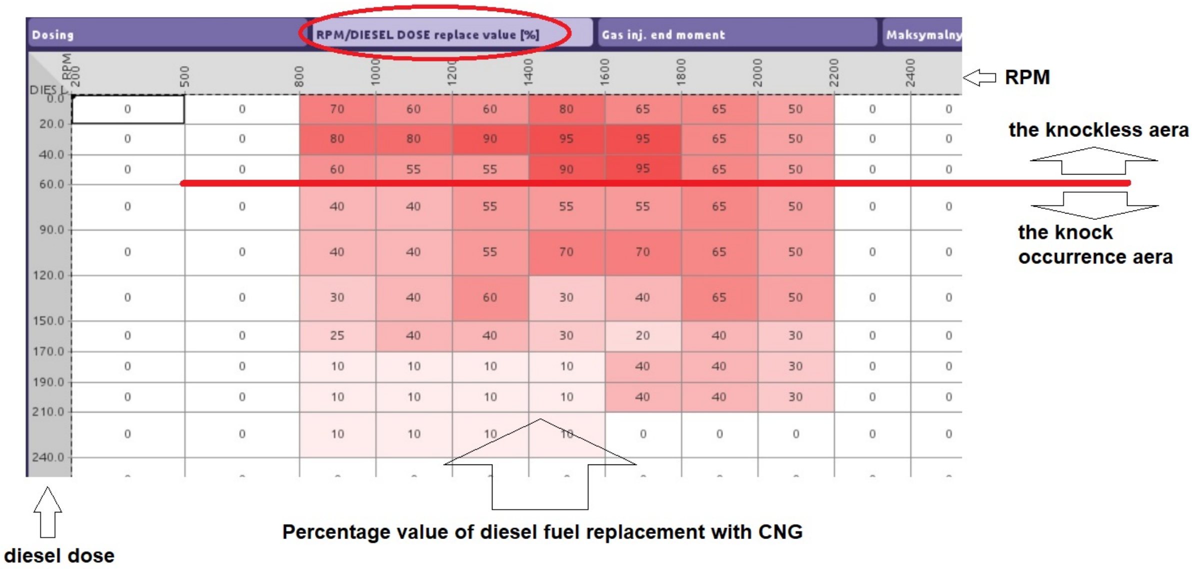


Figure 12 Screenshot from the gas controller software

Source: Authors' archive

3.2. Performance

Figures below (no 13 and 14) shows the values of the torque in a function of hourly fuel consumption for single- and dual-fuel operation for 2 constant rotational speeds.

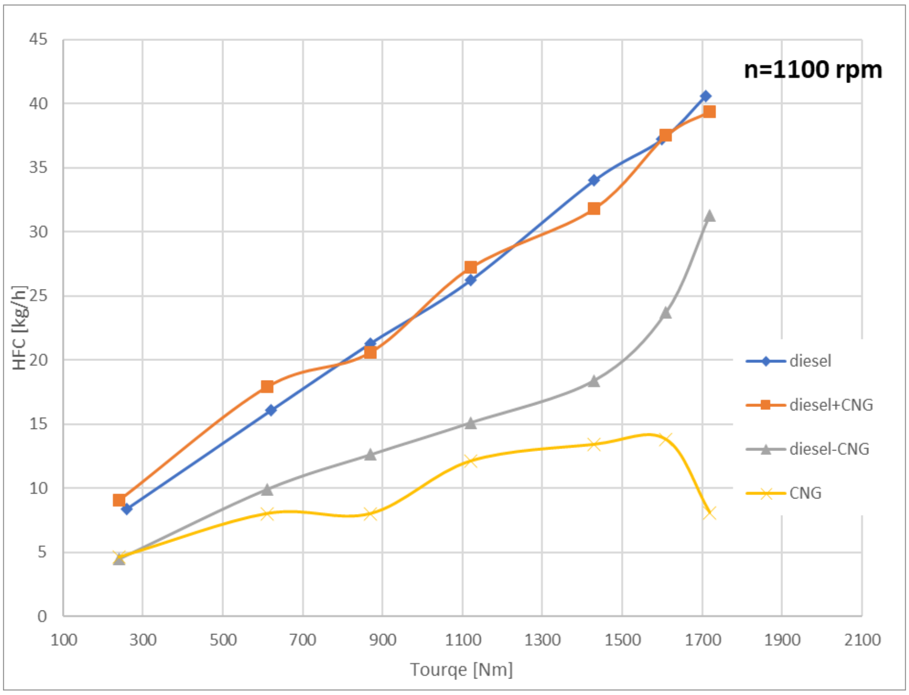


Figure 13 HFC and torque chart for operation on the base fuel and in the dual-fuel mode at 1100 RPM

Source: Authors' archive

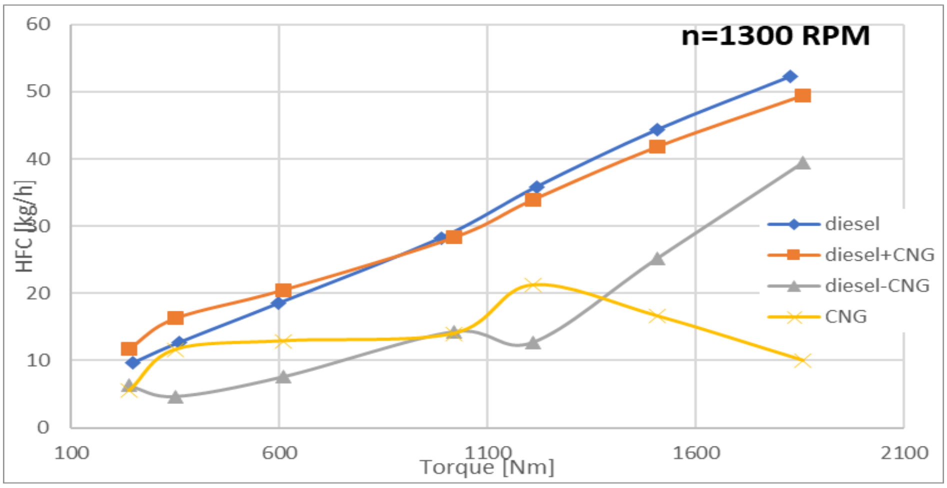


Figure 14 HFC and torque chart for operation on the base fuel and in the dual-fuel mode at 1300 RPM

Source: Authors' archive

3.3. Discussion

Research has shown that the distinct point at which knocking occurs is related to the fuel exchange rate and engine load. With increasing boost pressure, the percentage of fuel replacement decreases due to the appearance of knocking combustion. Figure 12 it can be seen in the representation of the calculated diesel dose, which corresponds to the possibility of generating upper torque values by the tested engine. Figures 13 and 14 also indicate a reduction in the possibility of fuel exchange near the maximum possible to generate torque. There is a clear discrepancy in the applicability of high fuel replacement rates. This situation is most probably caused by the fact that by indirectly introducing gas fuel into the intake system of the engine, it fills the space that was originally distorted in the diesel engine for air load. Thereby, as it were, the engine becomes overloaded with the gas-air mixture, which ultimately causes the resulting end gas knocking combustion.

3.4. Knock reduction methods

The incidence of knock can be avoided by a number of possible design and operational measures. For example, by: reducing the temperature of the mixture and the water jacket, delaying pilot injection, decreasing the compression ratio - they could undermine pilot ignition and the CI operation. The most appropriate way to avoid knocks (legitimate economic law and without excluding technological interference) is controls of the composition of the gas fuel mixtures, characteristics of the pilot injection or using EGR. As a general rule, an effective procedure to reduce the frequency of knocking, if this possible, is optimal distribution of gas fuel-air ratio with good stratification of gas components in the cylinder, with the reactive, leaner gas-air mixtures being in the regions of the pilot's ignition means where there are richer mixtures. This would require control of the gas distribution so as not to obstruct the ignition of the pilot fuel or to encourage the spontaneous combustion of areas adjacent to the pilot, while reducing the tendency of the charge away from these centres to self-ignite despite the high rate of increase in cylinder pressure and temperature [3, 5, 11].

Engine knocking combustion cannot be permanently eliminated, but there are many solutions to minimize it. In the case of converted engines, a second injection system is often extra added and minor changes are made to the equipment of the engine and the control system, which was also the case in the engine discussed in this paper. Taking this into account, only a few solutions are economically viable in dual-fuel converted engines. In addition to parameters that are difficult to improve, such as the material of the engine-head or the combustion chamber shape, for these changes that are economically acceptable, most cases the following can be used:

- fuel replacement ratio,
- gas injection advance,
- boost pressure,

In this discussed case, the most economically viable solution chosen by the authors of this study was to reduce the boost pressure through the use of a bypass engine intake circuit (figure 15). Research on its influence on the possibility of increasing fuel replacement ratio is underway.

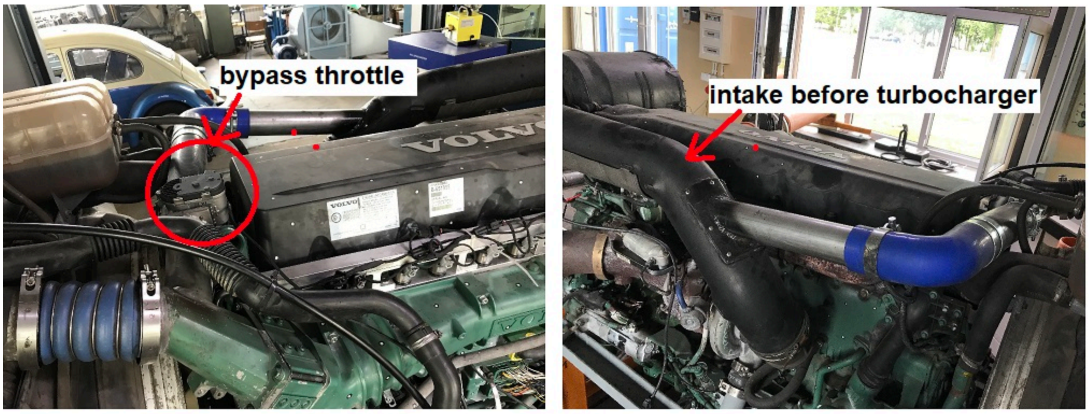


Figure 15 Construction of the bypass lowering engine's boost pressure

Source: Authors' archive

4. CONCLUSION

It is difficult to compare the results of the exchange coefficient and its impact on knocking combustion in the presented research with external results of other researchers, due to the experimental type of installation and the injection system, which is not commonly used on the market. This short research paper shows that sequential pre-intake valve CNG injection has great potential for use in a dual-fuel engine system where the pilot diesel acts as an ignition source in a compression-ignition engine. It is possible to recreate almost similar engine performance in such a system. It also has a positive effect on exhaust gas emissions, but to do so the fuel replacement in the operation should be as high as possible. The literature deals with knocking problems in a diesel-CNG dual-fuel engine. Empirical studies also confirmed the problem of dual-fuel knocking, in particular when trying to obtain high values of torque and with high load. More work needs to be done to reduce or eliminate knocking in an effective manner that maintains good engine performance and minimizes exhaust emissions. The authors' next step is to investigate the effect on the replacement ratio by lowering the boost pressure.

REFERENCES

[1] Heywood, J. B.; Internal Combustion Engine Fundamentals, Second Edition, McGraw-Hill Education, USA 2018, 519-597;
[2] Husted, H. L.; Guenter K.; Schilling, S.; Weber C. Direct Injection of CNG for Driving Performance with Low CO2. 23rd Aachen Colloquium Automobile and Engine Technology 2014.
[3] Karim, G. A.; Dual-fuel diesel engines, CRC Press, New York, USA 2015
[4] Karim, G. A.; Fuel Energy and the Environment, CRC Press, Boca Raton, FL, USA 2012
[5] Karim, G. A.; Klat, S. R.; Journal of the institute of Fuel, 39, 1966, 109-119;
[6] Kuiken, K. Gas- and dual-fuel engines for ship propulsion, power plants and cogeneration. Book I: Principles, Target Global Energy Training, PJ Onnen, The Netherlands, 2016, 1-488;

[7] Li, H.; Journal of Energy and Power, 220, 2005, 459-473;
[8] Li, S. C.; William, F. A.; A reduced Reaction Mechanism for Predicting Knock in Dual Fuel Engines, SAE Paper 2000-01-0957, 2000
[9] Li, W.; Liu, Z.; Wang, Z. Experimental and theoretical analysis of the combustion process at low loads of a diesel natural gas dual-fuel engine.Energy2016,94, 728–741.
[10] Ryan, T. W.; Callahan, T. J.; King, S.R. Engine Knock Rating of Natural Gases-Methane Number, ASME Journal of Engineering for gas Turbines and Power, 115, 922-930;
[11] Stoumpos, S. Marine dual fuel engine modelling and parametric investigation of engine settings effect onperformance-emissions trade-offs.Ocean Eng. 2018
[12] Website, access (05.06.2021): https://gazeo.pl/informacje/instalacje/gazodiesel/Diesel-Dual-Fuel-by-SCALMAX-to-ekologia-ekonomia-i...,artykul,10286.html
[13] Zulkiflia, F. H.; Fawzib, M., Osman, S. A.; A Review on Knock Phenomena in CNG-Diesel Dual Fuel System, Mechanics and Materials Trans Tech Publications, Switzerland, Vols 773-774 (2015) pp 550-554 (2015).
[14] Available online 12.07.2021: https://primeserv.man-es.com/docs/default-source/shopwaredocuments/dual-fuel-upgradedf528d94584746ca88a3584ecde70a0a.pdf?sfvrsn=df15cb54_4
[15] Available online 12.07.2021: https://www.cimac.com/cms/upload/events/cascades/cascades_2014_busan/presentations/Presentation_Session2_AVL_CASCADES_Busan_Oct2014_Harald_Schlick.pdf
[16] Available online 12.07.2021: http://www.gascar.pl/diesel-na-cng/
[17] Available online 12.07.2021: http://eko-pal.com.pl/diesel-na-gaz/

PORT OF SPLIT: IMPACT OF COVID-19 ON CARGO TRAFFIC

Maja Čović
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: mcovic@pfst.hr

Toni Meštrović
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail:

Josipa Bojčić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail:

Gorana Jelić Mrčelić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail:

UDK 656.615(497.5Split)
616-036.21"2019"

Summary

The appearance and spreading of coronavirus (COVID-19) brought significant economic and health crisis. Pandemic has affected global economy and financial markets as well as almost every other industry in the world. This paper observes impact of pandemic on cargo traffic in Port of Split. Adverse effect include declined income, as well as fall in cargo traffic. Although government has implemented rules to prevent spreading of the infection, those rules have negative impact on other parts of economy. The COVID-19 pandemic has underscored the global interdependency of nations and set in motion new trends that will reshape the maritime transport landscape. The aim of this paper is better understanding of effect pandemic has on cargo traffic, which can contribute to future improvements. Data used in this paper are obtained via Split Port Authority, and primarily show trends in cargo terminals of the Port of Split.

Keywords: COVID-19, pandemic, cargo traffic, ports, trends

1. INTRODUCTION

Global pandemic of COVID- 19 has huge negative impact on maritime sector, which caused significant decline in cargo traffic in ports around the world. This paper is observing situation and trends in Croatia, Port of Split. Since the establishment of the Port of Split, investments have been made in its infrastructure with the aim of improving passenger and cargo traffic at the Port of Split. The natural position and size of the port of Split enabled its rapid development and it became a port of special – international economic interest for the Republic of Croatia (Split Port Authority). Cargo flow in the last decade has put the port of Split in the third place at the national level after the ports of Rijeka and Ploče. The appearance of the coronavirus (COVID-19) triggered a global health and economic crisis with wide ranging implications for maritime transport and trade. Restrictions introduced in response to the pandemic have caused negative impact on ports, as well as cargo traffic (UNCTAD, 2020). The Port of Split is experiencing the emergence of the corona virus, and economic decline. It is therefore essential to provide an overview of current cargo traffic indicators, trends and capacities.

2. CARGO TRAFFIC IN THE PORT OF SPLIT

The Port of Split was focused on transshipment of all types of cargo, except containers, until 2006. Then, the authority of the port saw an opportunity and made a decision to initiate the containerization procedure, the establishment of container traffic in the port of Split. At that time, terminal contracts were concluded with leading container shipping companies. The port of Split has several specialized terminals with facilities for: general cargo, bulk cargo, conditioned cargo, RO-RO cargo and containers.The bulk cargo terminal has an area of 21600 square meters of which 10000 are open and 11 600 are closed warehouses. Length of the operational shore is 550 meters, and the depth of the sea at all berths is 11 meters so the port can receive ships up to 40 000 tons carrying capacity. The most frequently handled loads are: sugar, salt, coal, cereals, fertilizer. In addition to loading and unloading, handling of goods, services such as sorting, palletizing, bagging and weighing cargo are offered at the terminal. The terminal is connected with the railway and road network of the Republic of Croatia so with the storage of goods is possible to carry out direct loading of goods from and into wagons and trucks. International standard dedicated to Quality Management Systems adopted in 2015 (ISO 9001: 2015) as well as other safety certificates for railway infrastructure management are implemented. The general cargo terminal handles various of cargo such as wood, stone, iron profiles, sheets, coiled wire, bags, pipes, and large pieces of cargo up to 100 tons, such as yachts, ships, crane parts, windmill parts and other. The container and RORO terminal is located in the eastern part of the Port of Split, with a berth length of 200 meters and depth of 11 meters. The port of Split is connected to most of the world's ports with a weekly feeder service that enables fast and affordable transport of goods to and from Split (Stjepić, T. 2019).

3. DYNAMIC OF CARGO TRAFFIC IN THE PORT OF SPLIT

Since the start of the COVID – 19 crisis, the Commission, the Member States and the shipping industry have been taking measures to ensure the continuity of operations and thus the security of supply (EMSA, 2020). Activities of the cargo traffic in the port of Split are located in the main cargo north port of Split, northern basins of the city including Vranjic – Solin basin, Kaštela A,B,C and basin Kaštela D. Activities of the cargo traffic in the port of Split are located in the main cargo north port of Split, northern basins of the city. Basins are equipped to accommodate different types of cargo as mentioned before. Cargo – handling equipment is one of the essential structural element in the production of the overall port service. The main cargo – handling equipment in the southern part of Vranjic – Solin basin includes three types of cranes intended for the usage on the different terminals. The other port equipment in the container terminal include container forklifts, reach stacker, container trailers, container truck, terminal tractor for container trailer and other mechanization relates to numerous forklifts, tractors, skid and wheel loaders (Vukić, L., et al., 2019).

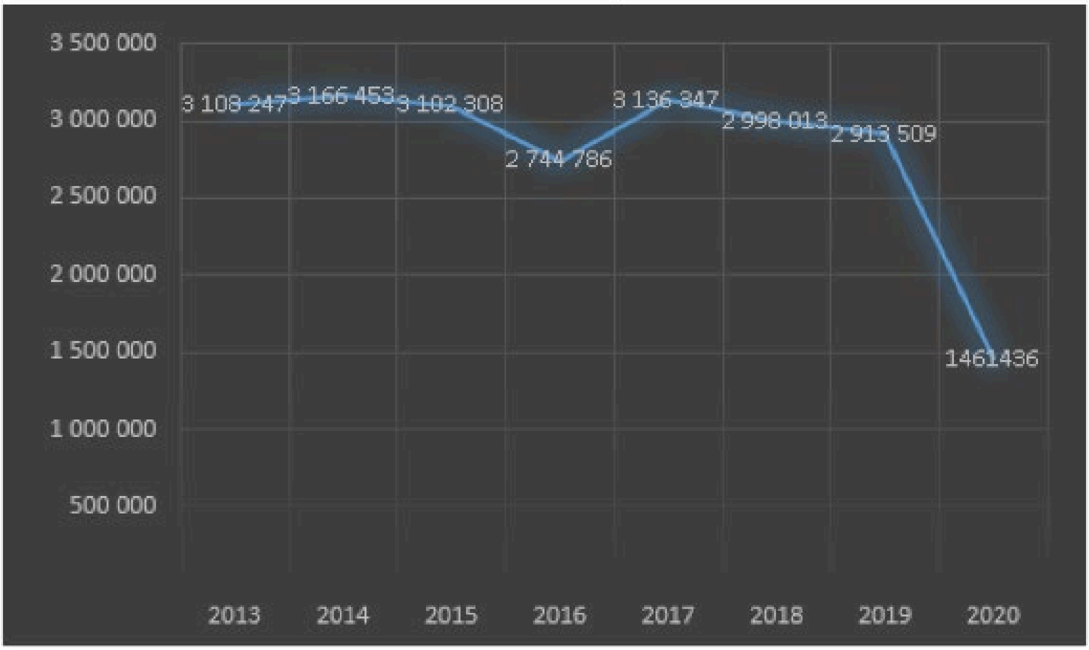


Figure 1 Graphical representation of cargo traffic (Source: Made by author using data provided from Split Port Authority 2021)

From interpretation of data provided from Split Port Authority, it can be concluded that COVID – 19 left significant negative effects on cargo traffic in the port of Split. Disruption is evident in global shipping, which also includes Croatia. There has been a decline in traffic, however, by studying at the market situation in recent years, it is evident that small decline in cargo traffic has been proceeding at the same rate as in 2017, 2018 and 2019, so the cargo traffic has been falling continuously even before COVID-19. However, that fall was not significant as the one in 2020. Therefore, the appearance of the corona virus left even greater negative effects with drastic fall in 2020, as shown in graphical representation of cargo traffic. This kind of fall is significant, as It is crucial for the EU that maritime transport services are provided without interruption, as 75% of goods entering and leaving the EU and 30% of goods on the internal market are transported by sea. In order to maintain economic activity, restrictive measures adopted in response to the COVID – 19 pandemic should have the least possible effect on the free movement of goods. Restrictions should not seriously disrupt supply cahins, basic services of the economies of the Member States and the EU as a whole (European Comision, 2020).

3. CONCLUSION

Covid-19 pandemic disrupted the balance in maritime transport, and negatively impacted market situation in Port of Split. Trends show drastic decline in cargo traffic, from almost 3 million tonnes to not even 1.5 million in year 2020. Considering every aspect of global industry is affected, and situation could become long term, which is why it is essential to track trends, and to minimise devastating consequences global pandemic has on industy. Impact of COVID-19 on every aspect of industry is intense, and devastating effects are visible on shipping industry. Port of Split also has significant loss, which is due to global pandemic.

REFERENCES

[1] Stjepić, T., "The maritime cargo ports in the Republic of Croatia", Polytechnic of Šibenik, Šibenik 2019, pp. 4-9

[2] Split Port Authority, (2020), Overview, available at: https://portsplit.hr/en/, [accessed 22 April 2021].

[3] Ivkovic, H., "Homeporting", IMSC 2010 Proceeding, Split, Croatia, May 2010, pp. 121-133.

[4] United Nations (UNCTAD), COVID – 19 and maritime transport: impact and responses, 2020, UNCTAD/DTL/TLB/INF/2020/1, avilable at: https://unctad.org/system/files/official-document/dtltlbinf2020d1_en.pdf, [accessed 27 April 2021].

[5] EMSA Impact of COVID 19 on shipping, avilable at: http://emsa.europa.eu/newsroom/covid19-impact.html, [accessed 28 April 2021].

[6] Vukić, L., Lušić, Z., Pušić, D., (2019), Trends and perspectives of cargo traffic activities I the port of Split, Naše More – "Our Sea", pp. 624-644.

[7] European Comision, Official Journal of the EU., (2020), Guidlines for the protection of health, repatriation and travel arrangements of seafares, passengers and other persons on board ships, (2020/C 119/01)

A PROPOSAL FOR A DESIGN OF NON-TECHNICAL SKILLS TRAINING FOR PARTICIPANTS OF THE SPECIAL EDUCATION PROGRAM FOR SEAFARERS

Jelena Čulin
University of Zadar, Maritime Department
Zadar, Croatia
E-mail: jculin@unizd.hr

Toni Bielić
University of Zadar, Maritime Department
Zadar, Croatia
E-mail: tbielic@unizd.hr

UDK 374.7:656.61

Summary

Similar to the situation in other safety-critical domains, a deficit in the non-technical skills (cognitive, social, and personal resource skills) of seafarers has been identified as a major cause for errors leading to maritime accidents and incidents. Therefore the need for demonstrating relevant knowledge and skills to perform tasks safely has been recognised by the maritime community and Bridge Resource Management (BRM) training is mandatory. Relevant content is a part of the curriculum for Work Organization and Management On Board, obligated course of the Special Education Program for seafarers, an alternative to an undergraduate degree program. Participants are active seafarers with various experiences and attitudes, and it is a challenge to transfer knowledge and skills effectively. This paper proposes a design of non-technical skills training for participants of the Special Education Program. Topics, instructional techniques, and assessment of the impact are discussed.

Keywords: Bridge Resource Management, non-technical skills, training

1. INTRODUCTION

Human failure is still the main cause of maritime accidents [12]. Analyses of the ongoing occurrence of unsafe acts reveal that poor safety outcomes do not result from a lack of technical skills only. Non-technical skills (NTS) enhance the way operators carry out technical skills. Therefore NTS: Managers' leadership, Communication, Teamwork (structure/processes (dynamics), Team leadership (supervisors), Situation awareness, Decision making, Coping with stress, Managing fatigue have been recognised as the important factors that contribute to safe and efficient performance in many safety-critical domains (aviation, healthcare, maritime, nuclear power, oil and gas, traffic control industries) [4].

Aviation first acknowledged that NTS are necessary to assure appropriate response of the crew to the situation, and introduced training and evaluation of NTS at the beginning of the 1980s [9]. Following the aviation sector, which implemented NTS training in Crew Resource Management (CRM) courses, the maritime community identified the same need and a maritime version of the CRM course for bridge officers was developed in 1992 [9]. Revision of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) in 2010 increased the relevant demands. The STCW Code includes requirements for deck officers to show competence in leadership and managerial skills and appropriate training courses (Bridge Resource Management, BRM training), which encompass guided content have been mandatory since 2017. Model courses Leadership and Teamwork and Use of Leadership and Managerial Skills have been designed to meet STCW requirements related to competencies at the operational and management level, respectively.

Special education program, introduced in 2011, enables Croatian active seafarers to meet requirements for certification of masters, chief mates, chief engineer officer and second engineer officer without the completion of maritime higher education. The content of the Work Organization and Management on Board, a required course of the Special education program, includes NTS themes. Participants have a minimum of 36 months of aggregated seagoing service as officers in charge of a navigational/engineering watch and their experience on board ships shapes attitudes and behaviours, which may differ significantly because they depend on many factors, including professional, organisational and national culture [10]. Therefore design and delivery of lessons related to BRM have to be carefully planned to achieve goals.

This paper presents some issues related to BRM training and proposes a design of the course. The choice and sequence of topics, instructional techniques, and options for assessment are discussed.

2. ISSUES RELATED TO BRM TRAINING

According to the literature, there is no proof that BRM training is effective, particularly in real-life operations [9]. BRM training evaluation is most often performed based on Kirkpatrick's hierarchy which includes four levels: reactions, learning (attitudes and knowledge), behaviour, and organizational impact, but studies investigating effects on behaviour and operation of the organisation are scarce [13]. Contrary to the results of most of the studies examining the impact of CRM training on aviation safety, most of the studies on the effectiveness of BRM training did not reveal changes in attitude, behaviour, and performance [9]. A comprehensive review of all relevant studies is beyond the scope of this paper. Findings from several studies are presented to illustrate the problems.

The effectiveness of the U.S. Navy's BRM training has been investigated by O`Connor [8]. A comparison between officers who had and had not attended BRM training revealed that, contrary to CRM, BRM training did not impact knowledge and attitudes. Saeed et al. developed a methodology to enable educators to quantitatively assess the impact of BRM training and concluded that it was ineffective, with a possible explanation that the study was based on simulator scenarios performed by students [11]. A study that assessed the impact of BRM training on reactions, knowledge, attitudes, behaviour, and performance in an experimental control group design indicated partially significant differences: no differences in attitudes, behaviour, and performance were observed [10]. A study investigating the effectiveness of BRM training by measuring subjective satisfaction level in Korea found that effectiveness was higher to the officers with the long than with short work experience and offered an explanation that officers with shorter service onboard focus on technical skills more [7]. BRM course was evaluated positively, increased knowledge, improved attitudes partly, but did not change the behaviour of participants in study performed by Tvedt et al. [13].

Recent reviews of research literature addressing BRM training identified several problems related to structure, delivery, and assessment of the effectiveness of BRM training and suggested some measures for improvement [2,6,9,14]. Analyses indicate that courses are mostly translated from other domains (mainly aviation), without adaption to the maritime domain that should be based on research on training needs, probably causing an observed lack of effectiveness [9]. Furthermore, a lack of a dynamic and comprehensive taxonomy of commercial bridge officers' NTS has been identified and further research on domain-specific knowledge on each relevant NTS has been proposed [2]. For instance, participants (bridge officers who participated in a BRM training course) of a study performed by Fjeld and Tvedt [1] identified types of NTS similar to other domains: Situation awareness, Decision-making, Stress management, Verbal communication, and Balanced leadership as key skills, but their understanding of some aspects differs from generic theory and syllabus [1].

Also, there is a possibility that programs should focus on different elements, and there is a need to identify processes that also improve safety and performance, such as adaptability and flexibility [6,9]. A stronger emphasis on the team instead of on the individual level and training for crews usually working together have been proposed to improve BRM training.

Theoretical topics relevant to specific operational needs should be presented during classroom training (lecturing, presentations, group tasks and dialogues, case studies), which should be combined with simulator-based training [14]. To obtain desired effects of simulator-based training, scenario design, performance evaluation, and debriefing should be carefully adjusted [9].

Suitable assessment and evaluation tools are necessary to properly evaluate the effectiveness of the course. For example, NTS taxonomy and behavioural markers of civilian bridge officers' NTS have been developed by Saeed et al. [11], mostly based on the NOTECHS (non-technical skills) system for assessing pilots' CRM skills developed by Flin et al. [3]. Saeed et al. [11] performed a literature review, interviewed senior officers, and developed a taxonomy with four categories (Teamwork, Leadership and management, Situational awareness, and Decision making) that include the following elements:

- Team building and maintenance
- Considering others
- Supporting others
- Communication
- Information sharing
- Authority and assertiveness
- Providing and maintaining standards
- Planning and coordination
- Workload management
- Task prioritisation
- Task delegation
- Initial crisis management
- Awareness of bridge systems
- Awareness of the external environment
- Awareness of time
- Assessment of situation
- Problem definition and diagnosis
- Option generation
- Risk assessment and option selection
- Outcome review

The authors [11] also identified behavioural markers for assessing skills based on outputs of interviews with twelve senior deck officers and then calculated the relative importance of each attribute using the analytical hierarchy process. Furthermore, they proposed five levels of performance (ranging from very good practice to very poor practice).

3. A PROPOSAL FOR THE DESIGN OF BRM TRAINING

Taking into consideration the above-mentioned factors that influence the effectiveness of the BRM training and the particularity of the Special Education Program for seafarers, course outline and teaching methods should be adapted to each student group. Adaptation can be made based on the overview obtained during a group discussion at the beginning of the course. It is necessary to identify previous experiences, attitudes, and understanding of NTS, which may differ significantly because participants usually work onboard various types of ships, they have different ranks, their seagoing service may vary from 3 to over 20 years, they are employed by domestic and foreign companies. The experience of the second author has shown that several issues are raised constantly at least by several participants, such as hierarchal communication, over-reliance or over compliance with the automated systems, inadequate workload management, problems caused by cultural differences. Sometimes those issues are seen as deeply rooted in the maritime culture, inevitable, and consequently measures related to them (including BRM training) futile. However, insight into the different perspectives and attitudes expressed by other participants during discussion sometimes transforms such views or enables identifying underlying reasons that should be emphasised during the course. For example, all participants may be familiar with the most common leadership styles, but unaware of the negative effects of some styles in certain situations if they have not experienced them. Therefore there is a need to tailor themes to meet needs. Regardless of the specific content, we propose the following sequence of the topics. First, lectures that provide necessary knowledge that supports learning in NTS are given. Core areas are Unsafe acts, Systems and technology, Workload management, and Toolkit (a set of methods that can be used for BRM) Lessons about unsafe acts are necessary at the beginning because understanding and awareness of factors that lead to unsafe acts enhance practice [5]. Therefore types of unsafe acts (errors and violations) and preconditions for unsafe acts (environmental factors, condition of operators, and personnel factors) are presented and discussed, concurrently with the role of the seafarers in building defences to prevent them. Area Systems and technology covers leadership styles, cultural awareness, the influence of the shipping companies on the crew management (the efficiency–thoroughness trade-off, management complacency), the influence of the technology on the occurrence of human error (technology complacency). Area Workload management contains lectures on real and perceived workload, pre-planning, prioritisation, and delegation. Examples and understanding of challenge and response, short-term strategy, and communication and briefings are given as tools for effective resource management. As a next step, during group discussions, participants are invited to consider factors that influence gaining and maintaining situation awareness, and impact risk assessment. Finally, we propose that the dependence of decision-making on all the above-mentioned factors is presented and discussed with participants.

After lectures, case studies on maritime accidents that involve discussed factors should be presented by the leader and analysed by participants. The most recent and less familiar accidents can be chosen to stress the relevance and enable a novel interpretation.

Because Work Organization and Management on Board is a required course of the accredited program, participants should receive grades. The oral or written exam can be used to assess necessary underpinning knowledge. Regarding the evaluation of leadership and teamworking skills, the STCW Code defines criteria such as "Communication is clearly and unambiguously given and received", "Effective leadership behaviours are demonstrated", "Necessary team member(s) share an accurate understanding of current and predicted vessel state and operational status and external environment", "Decisions are most effective for the situation". They are formulated taking into account that social skills Teamwork and Leadership and management can be directly observed, while cognitive skills Situation awareness and Decision making are not directly observable and must be inferred from observable behaviours [3]. Special Education Program for seafarers does not contain course Onboard training that could be used for evaluation during navigation. Therefore the BRM simulations, followed by a debriefing session are used to gather data on the NTS performance. In our case, Transans NaviSailor Full mission bridge simulator v5.35 is used because it enables recreating real situations. Furthermore, conducted exercises are recorded and can be replayed, enabling combining video analysis with direct observation of performance during exercises. A set of scenarios for the assessment has to be developed and prepared, taking into account that participants need time to familiarize themselves with the simulator and that the attention should not be on technical skills. Scenarios of real accidents may be selected and adapted to emphasise the importance of NTS in operations.

Post-simulation debriefing sessions underpin learning and provide a starting point for the evaluation process.

NTS taxonomy and behavioural markers of civilian bridge officers' NTS developed by Saeed et al. [11] may be used to evaluate competencies as defined in the STCW Code. However, due to limited time, the assessment of all proposed elements may be unwieldy. Also, the course does not lead to certification, which allows a flexible process. Given the interdependence of the various NTS and the fact that Teamwork and Leadership and management skills facilitate Situation awareness, which enables safe decisions, first Decision-making elements may be evaluated. Descriptions of desired behaviours are "Gathers all information to identify the problem, Full discussion of probable causal factors with team members, States all alternative options, Asks team members for a wide range of options, In-depth discussion of limiting factors with team members, States and confirms all selected options, Complete checking of the outcome against the plan" [11]. Then, based on the results, other, mutually exclusive elements for evaluation can be chosen.

Finally, a group discussion on the organisation, presentation, and usefulness of the course is held, and participants are encouraged to propose improvements.

4. CONCLUSION

Particularities of the Special Education Program for seafarers demand a different approach to the organisation and delivery of BRM training in comparison to the undergraduate program in nautical studies. Experienced seafarers have more knowledge, but possibly adopted certain behaviours and developed attitudes that hamper learning. Therefore BRM training should be tailored to each group to improve effectiveness and flexible delivery is desirable.

Future research should address the effectiveness of the proposed design. Appropriate questionnaires for assessing knowledge and attitudes before and after training and procedures for detecting changes in behaviour and performance should be developed.

REFERENCES

[1] Fjeld, G. P., & Tvedt, S. D. (2020). How do BRM-training participants understand non-technical skills? WMU Journal of Maritime Affairs, 19(2), 235–269. https://doi.org/10.1007/s13437-020-00198-9

[2] Fjeld, G. P., Tvedt, S. D., & Oltedal, H. (2018). Bridge officers' non-technical skills: A literature review. WMU Journal of Maritime Affairs, 17(4), 475–495. https://doi.org/10.1007/s13437-018-0158-z

[3] Flin, R., Martin, L., Goeters, K.-M., Hörmann, H.-J., Amalberti, R., Valot, C., & Nijhuis, H. (2003). Development of the NOTECHS (non-technical skills) system for assessing pilots' CRM skills. Human Factors and Aerospace Safety, 3(2), 97–119.

[4] Flin, R., Winter, J., Sarac, C., & Tomas, M. A. R. (2009). Human Factors in Patient Safety: Review of Topics and Tools. https://abdn.pure.elsevier.com/en/publications/human-factors-in-patient-safety-review-of-topics-and-tools

[5] Gordon, M. (2012). Building a theoretically grounded model to support the design of effective non-technical skills training in healthcare:The SECTORS model. Journal of Contemporary Mediacal Education, 1(2), 77–82.

[6] Havinga, J., De Boer, R. J., Rae, A., & Dekker, S. W. A. (2017). How Did Crew Resource Management Take-Off Outside of the Cockpit? A Systematic Review of How Crew Resource Management Training Is Conceptualised and Evaluated for Non-Pilots. Safety, 3(4), 26. https://doi.org/10.3390/safety3040026

[7] Hong, S. K., & Kim, H. (2016). Bridge Resource Management Training Programs in Korea and Their Effectiveness. Journal of the Ergonomics Society of Korea, 35(4), 237–245. https://doi.org/10.5143/JESK.2016.35.4.237

[8] O'Connor, P. (2011). Assessing the Effectiveness of Bridge Resource Management Training. The International Journal of Aviation Psychology, 21(4), 357–374. https://doi.org/10.1080/10508414.2011.606755

[9] Praetorius, G., Hult, C., & Österman, C. (2020). Maritime Resource Management: Current Training Approaches and Potential Improvements. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 14(3). https://trid.trb.org/view/1757076

[10] Roettger, S., Vetter, S., & Kowalski, J. T. (2016). Effects of a classroom-based bridge resource management training on knowledge, attitudes, behaviour and performance of junior naval officers. Wmu Journal of Maritime Affairs, 15(1), 143–162. https://doi.org/10.1007/s13437-014-0073-x

[11] Saeed, F., Wall, A., Roberts, C., Riahi, R., & Bury, A. (2017). A proposed quantitative methodology for the evaluation of the effectiveness of Human Element, Leadership and Management (HELM) training in the UK. WMU Journal of Maritime Affairs, 16(1), 115–138. https://doi.org/10.1007/s13437-016-0107-7

[12] Tavacıoğlu, L., Eski, Ö., Demir, B., Gökmen, N., & Algan, M. (2020). The non-technical skills of bridge officers on ship navigation: An assessment in terms of interpersonal skills. Indian Journal of Science and Technology, 13(8), 4587-4594.

[13] Tvedt, S. D., Espevik, R., Oltedal, H. A., Fjeld, G. P., & Mjelde, F. V. (2018). Can you teach an old seadog new tricks? Experimental evaluation of BRM training in the commercial fleet. 164-179. https://fhs.brage.unit.no/fhs-xmlui/handle/11250/2568394

[14] Wahl, A. M., & Kongsvik, T. (2018). Crew resource management training in the maritime industry: A literature review. WMU Journal of Maritime Affairs, 17(3), 377–396. https://doi.org/10.1007/s13437-018-0150-7

OIL POLLUTION OF THE MEDITERRANEAN AS A RESULT OF MARITIME ACCIDENTS

Marko Đorđević

Institution: Faculty of Maritime Studies, University
Rijeka, Croatia
E-mail: marko.dordevic@gmail.com

Žarko Koboević

Institution: University of Dubrovnik
Dubrovnik, Croatia
E-mail: zarko.koboevic@unidu.hr

UDK 504.5:665.6/.7 : 656.61.085 (262)

Summary

Contamination with oil from ships has the most significant consequences for flora and fauna. The spill of oil and oil derivatives significantly endangers the biodiversity of the affected area. Knowing the weathering process is crucial to prevent marine pollution from ships and other marine facilities. The presentation of previous maritime accidents adopts lessons and new knowledge that help intervene in oil and other marine pollution. It is also vital to know specialized equipment to remove contaminants and react quickly. The Mediterranean is one of the largest transport areas in the world. Some countries have natural gas, the explantation of which is growing day by day. Preventing marine pollution in the Mediterranean contributes to the development and preservation of the world economy in general.

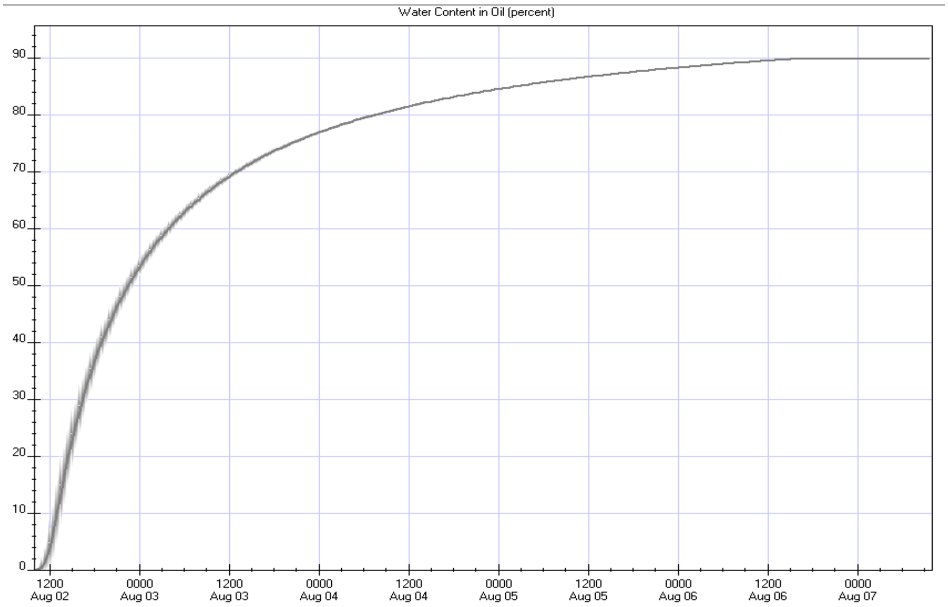
Keywords: Risk assessment, Mediterranean, Pollution equipment

1. INTRODUCTION

In maritime transport by sea we encounter various types of cargo with different properties. Each load affects the flora and fauna differently. Pollution of the sea with oils from liquid cargo ships has by far the greatest effect of damage to flora and fauna. For this reason, it is extremely important to assess the possible dangers of spilling oil on the sea surface. Production of oil and other petroleum products is on the rise. The standard of living of people all over the world, cars, ships still consume a lot of oil. Petroleum products play a major role in the market in general. Oil Tanker Spill Statistic 2020 estimate that over 50 % of all maritime accidents that result in pollution are due to the human factor. But major maritime accidents have been declining in recent years and the pollution that occurs is mostly minor. The most common pollutants by the ships are below 7 tons, which means the discharge of oil from smaller boats in ports. It is important to point out that large oil pollution attracts the attention of people in general as well as the media and journalists. The transport of liquid cargo is increasing every day. With more oil transported by sea, the risk of pollution also increases. Tankers Haven and Erica have historically significantly influenced marine ecology. Preventing the spread of oil when moving on the sea surface is crucial. The article's subject, historical presentation of sea pollution in the Mediterranean, real-time oil aging processes. The research objects are tankers for the transport of oil, transport, and transport through the Mediterranean. The goal of the paper is to describe some of the most significant oil spill accidents in the Mediterranean.

2. OIL WEATHERING MAIN FEATURES

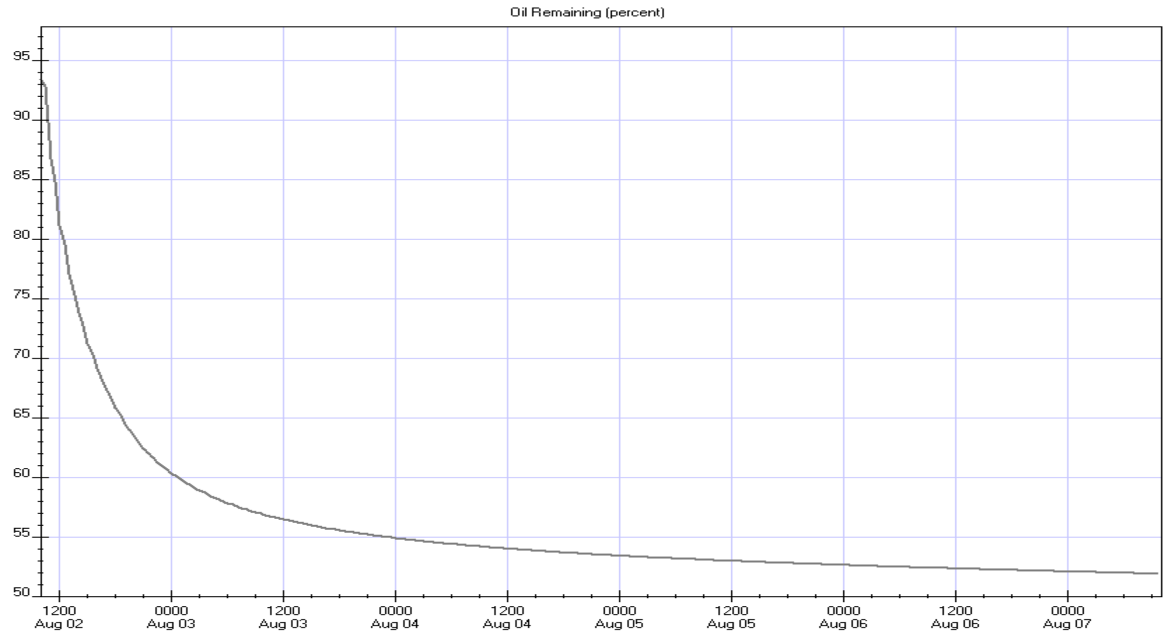
The weathering process refers to the changes that occur to oil as it spends time in the environment. Emulsification is a term commonly used to create a water-in-oil emulsion. The emulsion that is formed is commonly called oil pollution mousse. The water content in the emulsion can be up to 90 %. Oil emulsification increases the total volume of material in this oil and further complicates the cleaning of oil from the sea surface [1]. Graph one shows Water content in the oil Arabian Extra Light.



Graph 1 Water content in oil Arabian Extra Light, Aramco

Source: Created by the Authors using Adios2 tool

Thus, operating personnel must use more of their effort and mechanization to remove such oil, which further raises costs. Due to the oil emulsion, the viscosity increases drastically in cases of sea pollution with gasoline or similar oil. The oil completely evaporates or is lost in the atmosphere. For this reason, most often, the intervention for sudden pollution of the sea is not necessary, but only the observation of that oil is performed. Evaporation occurs within a few hours of the oil spilling into the sea surface. Volatile fractions of oil are lost in the atmosphere. The rate of oil evaporation is determined by the type of oil spilled, wind speed and strength, and ambient temperature. The turbulent sea promotes evaporation. The rest of the oil that remains on the sea surface has a higher density and is more viscous. Most crude oils lose up to 40 % of their volume by evaporation. Heavy propellants, i.e., bunkers on ships, show small losses by evaporation. In a few days, light crude oils can be reduced by to 75 % of their initial volume. While light refined products such as gasoline, light diesel evaporate completely and most often, the cleaning action is not necessary but just observing the oil to avoid mixing with some other material and thus endangering and polluting the area. Losses due to dissolution are relatively small because most hydrocarbons from mineral oil, i.e., oil, are poorly soluble in seawater. The most soluble components are at the same time the most volatile. The process is relatively long, and the toxic effects of the spilled oil are due to dissolution [2].



Graph 2 Oil remaining

Source: Created by the Authors using Adios2 tool

Dispersion is an essential component that needs to be well understood and analyzed to clean the affected area as effectively as possible, Waves and turbulence break the oil into droplets. Smaller droplets remain in suspension, while larger droplets rise again to the surface of the sea. The speed of the dispersion itself depends on the type of oil that is poured on the sea surface and the state of the sea on which the oil moves. The rate of natural dispersion can be increased by applying chemical dispersants to liquid, floating oil. Attention should be paid to the fact that chemical action has a specific time to be observed to be effective [3]. Sedimentation, some heavy raffinates sink in a sea of low salinity or freshwater. Most crude oil does not sink in the sea. The incorporation of suspended solids into so-called weathered oil promotes oil immersion. Temperature can affect the buoyancy of the oil itself on the sea surface. Finally, it is essential to mention the biodegradation of the oil itself. Biodegradation occurs regularly. Numerous bacteria, fungi, and yeasts present in the marine environment can biodegrade hydrocarbons. The speed depends on the temperature, the presence of nutrients, most nitrogen and phosphorus, oxygen, and the type of oil itself. Lighter components are biodegradable faster. Microorganisms act at the boundary between oil and water. Dispersion of oil in droplets promotes biodegradation. Knowledge of the oil's fundamental physical and chemical properties is necessary to predict the behavior and movement of oil slicks on the sea surface. Knowing and knowing the above properties of the oil can significantly facilitate decision-making about intervention operations. If the oil properties are not known, it is necessary to take a sample and analyze it to obtain the characteristics of the oil and thus know how to proceed further in response to sudden pollution of the sea from oil and other dangerous and harmful substances. Attention should also be paid to adverse weather conditions, cold, heat, wind that can demotivate and complicate intervention actions to sudden marine pollution. Procedures to prevent the spread of oil can be taken even before the spill, which is an obligation where there is a potential danger of spillage and endangering the essential resources.

3. TRANSPORT IN THE MEDITERRANEAN

Another strong traditional economic sector in the Mediterranean is transport, specifically maritime transport, that shows figure 1.

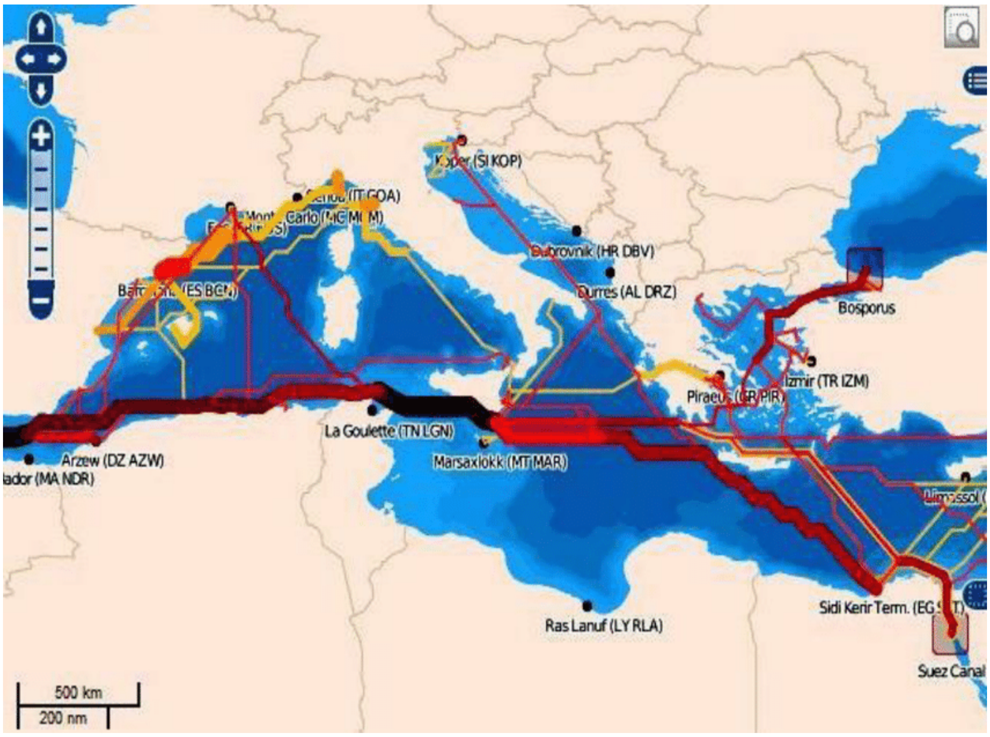


Figure 1 Transport in the Mediterranean; Source [4]

Yellow lines refer solely to cargo and container ships, while the red mainly to tankers but also to all other types of ships. Additionally, the thickness of the line represents the number of ships following the specific route. Oil and gas exploration and exploration activities in the Eastern Mediterranean. The extensive maritime transport of large quantities of crude oil comes from:

- From the Middle East to ports in Europe and North America via the Suez Canal.
- Between the Mediterranean and the Red Sea.
- Through the Strait of Gibraltar.
- Between the Black Sea and the Mediterranean through the Turkish Straits.

It is important to note that the Mediterranean was not known as a significant area for the offshore industry and natural gas until recently. The situation changed significantly with the discovery of natural gas-rich regions of Israel, Palestine, Cyprus, and Egypt. With the rise of the offshore industry, there has also been a significant risk of marine pollution. Numerous administrative bodies have also been established to regulate the rights and modalities of gas exploitation in the Mediterranean area. By the Oil Tankers Spill Statistic-ITOPF It is essential to note the primary sources of oil pollution in the Mediterranean:

a) Tankers and Containerships
b) Offshore platforms (drilling rigs etc…)
c) Pipleines
d) Releases of bunker fuel
e) Ferries
f) Tourists
g) Military activities
h) Fishery

Distribution of pollution emergencies managed Average data in 10 years time 2006-2015 according to the geographical area:

i. Mediterranean Sea and Gibraltar Strait = 61 %
ii. The Atlantic = 46 %
iii. The Canaries = 13 %

Maritime traffic can cause oil pollution either coming from accidents or operational discharges. The most common source of oil pollution from maritime traffic is generated as a result of vessel operations [5].

3.1. Oil pollution in the Mediterranean sea

MT Haven tanker after explosion on April 11. 1991. of the coast of Genoa, Italy. Because human error. The disaster spilled more than 44 million gallons of crude oil into Genoa harbor and the adjacent Tyrrhenian Sea [6].

Fire booms are a specialized containment boom. Containment booms are specially designed floating barriers that are used to prevent an oil or chemical spill form moving freely across a water surface. A skimmer is a device for recovering spilled oil from water's surface. Skimmers may be self-propelled, used from shore, or operated from vessels. Figure two shows the fire on the ship Haven.

Figure 2 Fire on the ship Haven; Source [7]

Figure 3 Fire booms; Source [7]

Figure three shows fire booms that are resistant to high temperatures to reduce sea and coastal pollution [8]. Around 10 am on April 14, the remaining stern section sank in 80 meters of water. When this section sank, the fire was finally extinguished after burning for more than 70 hours. Let's take that the characteristics of developed countries are high capital equipment and increase in GDP. It is concluded that an accident like the ship Haven can significantly damage the economy of a nation [9]. The Maltese tanker *Erika* was 24 years old. From the economic point of view her old age was an advantage, i.e. her chartering cost was 50 % lower than that of a newer tanker. Parts of the wreck sank at the distance of 10 km from each other. In the bow that sank there were still 6,400 tons of cargo, and in the stern 4,700 tons.

Figure 4 Pollution of the coast from the ship Erica; Source [10]

Figure four shows the pollution of the coast and the specialized staff for collecting oil from the beach [10].

Vessels which participated in clean-up Erica operations were chosen due to their characteristics, equipment-wise and design- wise. All of them had to:

- Be able to cope with unfavorable weather conditions like rough sea.
- Be rapidly available at clean-up sites.
- Have sufficient storage capacity to collect oil.
- Be fitted with equipment suitable for storing and discharging collected oil [11].

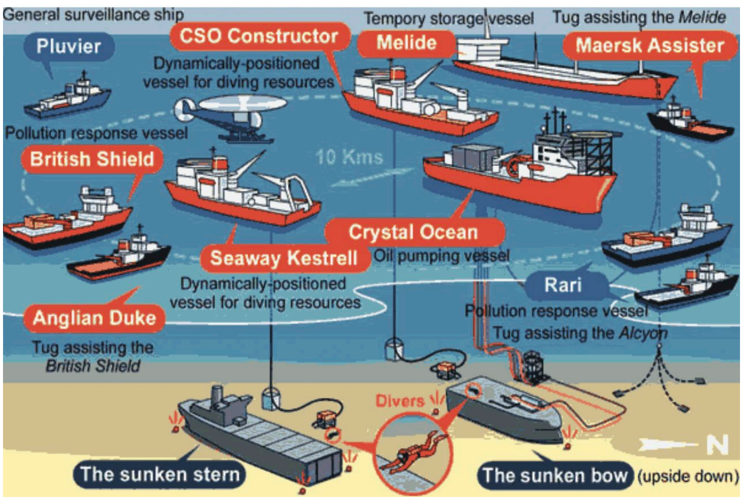


Figure 5 Vessels and equipment used in around the Erika wrecks; Source [12]

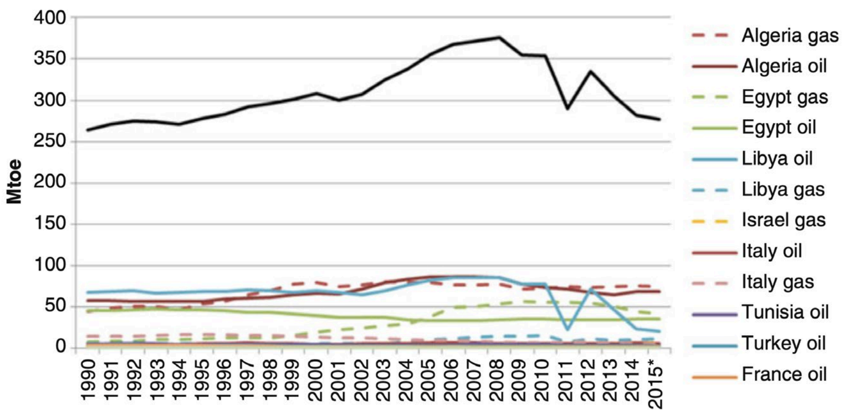
Figure five shows the vessels, the equipment used to prevent further pollution of Erica ship. The ship MT Prestige, in 2002, broke into two parts in the morning hours of November 19, about 170 nautical miles west of Vigo. Both two sections of the ship sank to a depth of 3,500m[12]. Apart from oil, the problem with interventions was also the problem of sinking the structure to great depths. In addition to the spilled oil, the mentioned remains of the ship were carried by the sea current, which additionally contaminated the entire water area and endangered flora and fauna. A good advantage is that the maritime accident happened in the winter, so the impact on flora and fauna was much smaller. Due to the presence of semi-aromatic hydrocarbons, the effects on plankton are still visible today. It is essential to add that it is the human factor to blame for maritime accidents in up to 75 % of cases [12]. Following the completion of actions to clean up the affected area, the European Parliament set up a Mare Committee community. A temporary community whose task was to investigate the Prestige maritime accident in detail to discover the causes of the accident. Prestige oil spill, the Prestige oil spill occurred off the coast of Galicia – Spain. The ship broke into two parts that sank to the bottom of the sea surface to a depth of 3,500m. The pollution happened in the winter.

Figure 6 Coastline affected by Prestige oil spills; Source [13]

Figure six shows the movement of oil on the sea surface.

3.2. Oil spills in the Adriatic sea

The Adriatic, as is the case for the entire Mediterranean. The Adriatic Sea was once the most important waterway for European trade[14].The amount of crude oil, products, and liquid chemical cargos transported via the Adriatic Sea currently amounts to some 70-80 million tons per year. Large vessel traffic is dense, and accordingly there is a great deal of operational pollution along with the constant threat of accidents[15]. Graph three shows the production of natural gas by Mediterranean countries



Graph 3 Total oil and gas production (onshore and offshore); Source [16]

3.3. Tanker collision risk assessment

Risk is a two-dimensional quantity, and it is a function of the probability of an adverse event and the consequences that that event will cause. From this follows a mathematical representation of risk.

From the formula, the notation p indicates the probability of occurrence of a specific event, while the notation C implies the consequence caused by accident [17]. Numbers between 0 and 1 express the numerical representation of the probability of a specific event, i.e., the probability of any event that will occur is between 0% and 100% [18]. For mutually exclusive events, the probability that any event will occur is the sum of the probabilities of the individual events. When intervening in extraordinary marine pollution, especially in the event of a collision, stranding, or another damage resulting from an oil spill, the commander of the operational staff has the primary task or obligation to ensure the safety of workers carrying out remediation of the affected part of the sea or coast. In addition to taking care of the safety of workers, the intervention commander is obliged to secure and protect the contaminated site from citizens and the surrounding population so that they do not come into contact with oil or a dangerous substance and thus endanger their own lives [19]. The commander must also inform the population about the incident and provide security measures and warnings. The most important thing is to act within the golden hour. This means that initial reactions and actions taken are crucial to the rapid clean-up and sustainability of safety itself. Accidents involving liquid cargo ships present the two most probable dangers that can endanger the environment, and most of all, human life itself. Both hazards need to be separated and analyzed separately to ensure the safety of operational staff. The most likely two dangers are: risk of fire and explosion and hazardous, flammable vapors.

The following section will analyze these hazards in detail, together with specialized equipment for removing oil pollution from the sea surface and the sea globe.

3.4. Fire and explosion hazards

The conditions under which a fire may occur, and therefore an explosion, must be met by the following three components, namely:

- combustible substance, the i.e., substance that supports combustion,
- oxygen,
- source of ignition, i.e., heat.

If we remove one condition from the above three ignition conditions, fire or uncontrolled burning will not be possible. When intervening to clean oil from liquid cargo ships, operational personnel must take care of the following components to reduce the risk of fire.

In potentially flammable areas, the following actions must not be taken when cleaning the oil, such as:

- use devices that can cause a spark of ignition,
- turn off electrical appliances with a jet of water, rather than using specialized foam,
- monitor the atmosphere with an explosimeter so that a potentially flammable room can be safely accessed [20].

4. SPECIALIZED VESSELS FOR THE PREVENTION OF SEA POLLUTION

Specialized vessels are specially designed and built to respond to seas due to pollution and can be used:

- ➢ preventing the spread and collection of spilled oil on the sea surface using dams and oil collection devices,
- ➢ spraying of chemical agents, i.e., dispersants,
- ➢ for the temporary storage of collected oil, until the transport of the port of acceptance,
- ➢ transfer of collected oil to another vessel or tanks on a ship or port.

Figure 7 Specialized vessel for oil pollution; Source [21]

Figure seven shows a specialized vessel responding to pollution [22]. The figure shows a specialized vessel designed to respond to sudden marine pollution. The vessel is equipped with skimmer devices for collecting oil and cranes that allow the removal of larger objects from the sea. Each country has its approach and requirements related to determining the characteristics of specialized boards for responding to sudden marine pollution [23].

5. PURPOSE OF BOOMS IN OIL POLLUTION

With the help of a dam, the oil stain is rounded off, and thus the oil is concentrated in one area. The oil does not spread further on the sea's surface, so collecting oil is much easier. For proactive protection of particularly endangered places that are of great economic importance, such as ports, beaches with hotels, biologically sensitive areas, dams are placed to prevent the penetration of oil into these areas. For any dam to be as effective as possible, the dam must be positioned so that the waves follow so that its upper part does not rise below the oil surface, and the lower part of the dam called the curtain edge must be above the boom lower oil edge. The success of a dam in preventing marine pollution depends on the conditions in which a particular dam is used, and any boom in deplorable conditions will inevitably have to fail and leak a certain amount of oil.

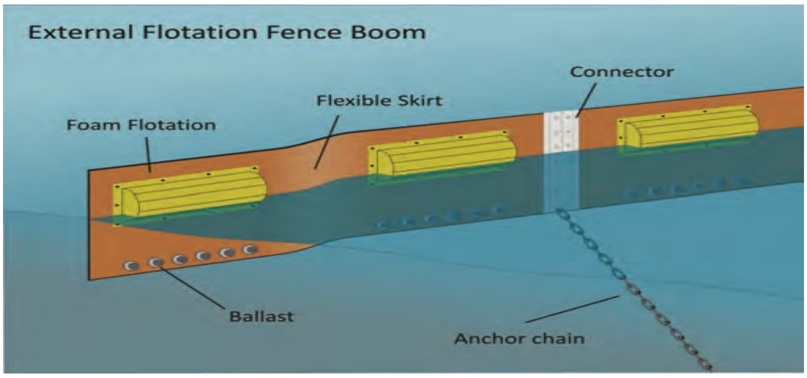


Figure 8 Curtain boom for oil pollution; Source [24]

In the water area where the oil is located, the gust of wind on the dam and the strength of the sea current is considered. Given the mentioned parameters, a dam is chosen, which can be a curtain in strong winds or a fence of fences in cases of rapid intervention on oil pollution.

5.1. Personal protection and natural hazards during oil spills

In cases of sudden pollution of the sea surface, it is necessary to obtain as accurate information as possible about the type of maritime accident. It is crucial to get information, which type of oil contaminates a particular area. Thus, the operational staff applies specific techniques to prevent the spread of oil further on the sea surface, and if the oil has the characteristics of dangerous cargo, the intervention plan for that cargo is followed. Initial information can also reach the nearby population. At the same time, operators are tasked with obtaining and asking as much information as possible about the maritime accident itself to find out the type of cargo and ship and take the necessary cleaning actions accordingly. In the event of a collision of liquid cargo ships, the first action is also the most important if it is possible to transfer oil from punctured tanks to undamaged tanks or temporary tanks at sea. If switching is not possible, it is necessary to perform if weather conditions allow and equipment stopping oil from the ship into the sea. In such situations, the commanders are obliged to provide all necessary information on the type of maritime accident, the type of cargo they are carrying, whether there are any injuries on the vessel and whether a specific part of the ship was affected by the fire [25]. Once the necessary information has been obtained, operational staff have five main options for intervening in the event of sudden marine pollution:

1. Action without the intervention of operational staff in the field. In cases where the oil does not move towards the economically essential resources of a particular country, if it is a volatile oil that will disperse naturally, or if weather conditions do not allow operational personnel to go to the field due to endangering their safety.
2. Collecting and preventing the spread of oil using specialized equipment.
3. The use of chemical methods, using dispersants that have the function of dispersing oil, or break down oil into particles and thus promotes natural decomposition.
4. Incineration method, in which fire dams and specialized vessels with trained personnel must be used.
5. Let the oil reach a specific side of the shore. If the weather conditions do not allow cleaning at sea or estimated that the repair costs are cheaper, then the oil can float to the shore, subsequently cleaned from the shore.

Operational personnel, led by the Pollution Cleaning Commander, must consider the hazards of interventions in the contaminated area. Contaminated animals can pose natural hazards. Which under the influence of shock can be violent towards a person and inflict severe wounds. The danger can also come from stings of wasps or bees, for example, where a specific person may be allergic [26]. It follows that the area affected by the oil should be specially secured and warning notices put up. Attention should also be paid to adverse weather conditions, cold, heat, wind that can demotivate and complicate intervention actions to sudden marine pollution. Procedures to prevent the spread of oil can be taken even before the spill, which is an obligation where there is a potential danger of spillage and endangering the essential resources. In any intervention, the working environment in which the operating staff performs the cleaning should always be performed in a team. This provides additional security. Personnel performing cleaning, oil, or shore oil intervention interventions must wear appropriate protective equipment. Equipment consisting of specialized gloves, helmet, work shoes with non-slip surface, goggles that protect against oil splashes in the eyes, work suit, and other equipment needed to carry out the cleaning action. If the oil comes in contact with the skin, rinse immediately with clean water and consult a doctor for further instructions. With timely cleaning action, organized operational staff led by the commander, proper use of pollution prevention equipment with appropriate protective equipment leads to successful action and response to sudden sea pollution with oils at sea or on land, i.e., the coast. Coastal type should also be considered, and appropriate equipment should be used to collect and prevent possible significant pollution. With the correct intervals for rest, with good organization of waste sorting, and all of the above, it leads to the safety of the operating staff performing cleaning actions. On the nautical charts, certain areas are specially designated as water areas of great economic importance, which must first be separated from oil pollution.

6. CONCLUSION

Knowledge of the characteristics of the spilled oil on the sea surface is an essential factor in applying appropriate actions of operational personnel's interventions to prevent oil pollution. Trained staff with regular training to clean oil pollution and gaining knowledge through their practice is the key to safe and effective cleaning of the sea and coast. It should be emphasized that each maritime accident and each oil pollution should be considered separately. Nevertheless, it should not be overlooked that every oil spill into the sea has similar consequences for flora and fauna and potentially for humans. With possible available equipment and experience, operational personnel will determine the approach to a particular maritime accident that results in an oil leak to the sea surface. From the analytical and graphical presentation using the ADIOS2 program, it can be seen that the fastest reaction and intervention to sudden oil pollution facilitates the collection of oil from the sea surface and thus eliminates the risk for all operational staff. Also, proper handling of personal protection and proper handling of specialized equipment and following the intervention plan leads to a reduction in the risk of pollution and thus leads to optimal action and protection of the marine environment.

The Mediterranean Sea lies between Europe to the North, Asia to the east, and Africa to the south. It is one of the most highly valued seas in the world. The Mediterranean Sea is one of the busiest in the world with, around 20 % of shipping trade and 10 % of world container traffic moving through it and around 200 million passenger movements annually. The population of the region is forecast to grow to 572 million by 2030 which will increase the environmental pressures.

REFERENCES

[1] Dorčić, I. (1987). Basics of cleaning oil pollution. Zagreb. Croatia.
[2] ITOPF. Available at: https://www.itopf.org/in-action/case-studies/case-study/haven-italy-1991/ [accessed 22/03/2021]
[3] Greekamerican. Available at: https://archive.greekamericannewsagency.com/2014/10/31/egypt-has-joined-greece-and-greek-cyprus-in-calling-for-turkey-to-stop-exploration-work-off-the-cyprus-coast/ [accessed 24/03/2021].
[4] Bigdata oil and gas. Available at: https://www.offshore-mag.com/production/article/14073657/northwest-europe-natural-gas-production-set-for-steep-decline [accessed 16/03/2021].
[5] IEMED. Available at: https://www.iemed.org/publication/the-components-of-maritime-transport-in-the-mediterranean/ [accessed 07/07/2021]
[6] Aukevisser. Available at: http://www.aukevisser.nl/supertankers/VLCC%20A/id1095.htm [accessed 03/07/2021]
[7] Kumar, A., Suresh, G. (2015). ''Weathering of oil spill: Modeling and Analysis''. ScienceDirect. Vol.4, pp. 435-442 – https://doi.org/10.1016/j.aqpro.2015.02.058
[8] Bralić,T., Slišković, M. (2006) The most significant tanker accidents. Split. Croatia.
[9] Ejatlas. Available at: https://ejatlas.org/conflict/erika-shipwreck-and-oil-spill-britanny-france [accessed 04/07/2021]
[10] Environmental Justice Atlas. Avaiable at: https://ejatlas.org/conflict/erika-shipwreck-and-oil-spill-britanny-france [accessed 21/05/2021].
[11] Grubesic,T., Wei.R., Nelson, J. (2017) ''Optimizing oil spill cleanup efforts: A tactical approach framework''. Marine Pollution Bulleti. Vol.125, pp. 318-329 – https://doi.org/10.1016/j.marpolbul.2017.09.012
[12] Cedre. Available at: https://wwz.cedre.fr/en/Resources/Spills/Spills/Erika/The-wreck-oil-pumping [accessed 04/07/2021]
[13] Harilaos, N. (2006) ''Maritime safety in the post-prestige era''. Mar Technol SNAME. Vol.43, pp 85-90- https://doi.org/10.5957/mt.2006.43.85
[14] Deutsche Welle (DW). Available at: https://www.dw.com/en/row-over-prestige-oil-spill-continues/a-1036218 [accessed 04/07/2021]
[15] Researchgate. Available at: https://www.researchgate.net/figure/Coastal-areas-affected-by-the-Prestige-oil-spill-given-in-black-in-northern-Spain_fig1_41622277 [accessed 12/04/2021]
[16] Perkovic, M., Harsch, R. (2016) ''Oil Spills in the Adriatic Sea''. JRC Publications Repository. Vol.2, pp 23-45- https://doi.org/10.1007/698
[17] Model Course (2005) ''Oil pollution, preparedness, response and co-operation, level 1. Second edition''. IMO. London, 2005. pp.168
[18] Winnem, J. (1999). Offshore Risk Assessment; Principles, Modeling and Applications of QRA Studies. Faculty of Marine Technology. Norway.

[19] Kristiansen, S. (2005) Maritime Transportation Safety Management and Risk Analysis. UK.

[20] Schein, A., Scott, J., Hodson, P. (2009) ''Oil dispersion increases the apparent bioavailability and toxicity of diesel to rainbow trout. Environmental Toxicology and Chemistry''. Vol.28, pp. 595-602 – https://doi.org/10.1897/08-315.1

[21] Ehrhardt, M. (2015) Mathematical Modelling and Numerical Simulation of Oil Pollution Problems. UK.

[22] Lazuga,K., Gucma, L., Perkovic, M. (2018) ''The model of optimal allocation of maritime oil spill combat Ships''. Sustainability. pp. 42-49 - https://doi.org/10.1997/08-313.1

[23] Ehrhardt, M. (2015) ''Mathematical Modelling and Numerical Simulation of Oil Pollution Problems''. Vol.2, pp. 351-352

[24] Grech, M., Horberry, T., Smith, A. (2002) ''Human Error in Maritime Operations: Analyzes of Accident Reports Using the Leximancer Tool, Key. Center of Human Factors and Applied Cognitive Psychology''. University of Queensland. Brisbane. 46th Annual meeting – https://doi.org/10.1177/154193120204601906

[25] Transportation research board. Avaiable at: https://journals.sagepub.com/doi/10.3141/2326-05 [accessed 07/07/2021]

[26] Environmental Justice Atlas. Avaiable at: https://ejatlas.org/conflict/erika-shipwreck-and-oil-spill-britanny-france [accessed 21/05/2021]

WOMEN SEAFARERS: A DISCOURSE ANALYSIS PERSPECTIVE

Milena Dževerdanović-Pejović
University of Montenegro, Faculty of Maritime Studies
Kotor, Montenegro
E-mail: milenadz@ucg.ac.me

UDK 331.101.232: 656.61
305-055.2

Summary

This paper studies the position of women seafarers on board ship using critical discourse analysis. Motivated by the notion that women have become more visible in the maritime sector, discourse analysis of texts about women seafarers showed women's complex roles regarding their career at sea and their life on shore. The corpus in this paper comprises online interviews retrieved from nautical sites and recognised news portals. Theoretical background in this paper relies on critical discourse studies and the notion of power, cultural scripts, and gender-related dominance in discourse. The aim of the analysis was to determine how linguistic exponents reflect the changing trends in the maritime sector regarding global gender-related movements, the impact of the mainstream media and women empowerment. The paper combines quantitative and qualitative approach. Statistical data were interpreted from the specific maritime working setting. We identified four concepts related to the status of women in shipping and then we analysed them individually. The results suggest that women have come a long way from their recognition as 'only and alone' to becoming equal with men in the predominantly masculine work setting such as a ship. The main contribution of this paper is to present a universal concept about women seafarers and to shed light on prevalent assumptions about women seafarers in certain seafaring societies resulting from special norms and values, geographic peculiarities, culture, tradition and collective mind-sets.

Keywords: women seafarers, discourse analysis, social media, masculine work settings.

1. INTRODUCTION

The rise of women in seafaring results from different currents linked to women's rights in various institutional fields. The first current is associated with the feminist movement, which among other issues, states that language reflects women's inferior social position [7, 8, 9]. According to Cameron [10, 11] and Sunderland [12] the language is mainly created in favour of men, which is evident on morphological and vocabulary level. The research on language usage differences between men and women blossomed in the late sixties after Lakoff's essay *Language and Woman's Place* was published [7]. In her dominance theory, Lakoff argues that women are recognised as wives, daughters or lovers, and are 'marked' members of social life. Changes in language regarding the naming policies for the jobs that are traditionally deemed masculine have impacted some nautical journals. In the world of literature, ships have always been referred to as 'she', while the terms 'ocean' and 'sea' have been considered 'male'. As of 2001, the editors of the traditional maritime journal 'Lloyd's List' have decided to refer to ship as 'it' [1]. Many journals and media resources have soon recognised these language-related inequalities and complied with the shipping industry's novelties, which opened up to women seafarers [13].

The feminist movement that has started in the nineties of the last century coincided with the economic need for the increased participation of women in the seafaring market. New institutional changes and household organisation contributed to the birth of modern labour economics and a change from a woman with a job to a woman with a career [14]. Diversification of job profiles provided the economic environment for disadvantaged groups, minorities, and women [15]. The stereotypical portrayal of women as passive, aesthetic-oriented, and occupied with children, has long pervaded human perceptions and media images in the nineties of the twentieth century [16]. Women's proactive role against male supremacy furthered gender inequality in male-dominated professions, childcare, sexual harassment, violence, and lifestyles in patriarchal societies [17].

The second current that accelerated greater participation of women in seafaring is related to global institutional changes. In this light, a series of activities implemented by the United Nations, the International Maritime Organization, the International Labour Organization and the World Maritime University raised awareness about women's discrimination, maternity leave rights, salary and women's living spaces in masculine-dominated workplaces. This led to adaptations of ship's spaces on merchant vessels. "The working conditions, the morale, and the atmosphere on board actually get better for everybody, including male seafarers" [18]. At the same time, the main organisation for women in shipping– Women's International Shipping & Trading Association with forty-nine national WISTA associations encourages women to get more prominent roles in the maritime sector. Other related organisations are International Seafarers' Welfare and Assistance Network (ISWAN), Women in Maritime Philippines (Wimaphil), Women in Maritime Associations Asia (WIMA). On the other hand, Kitada [19] underlines the problem of gender segregation and female underrepresentation in the seafaring profession, and argues that shipping companies do not regulate gender-related work policies. Thereby, differences in managing styles between men and women in male-dominated working environment are worth exploring [20].

Integration into a seafaring profession varies worldwide. Compared to Italian women, Swedish, Danish, British, German, and Norwegian women seafarers are more involved in seafaring. Yet, Scandinavian women are not attracted to working as seafarers [21]. The countries with low participation of women in seafaring are India, Australia and New Zealand. The Philippines provides an incredible number of seafarers (around 25 000), but only 225 are women. A low percentage of women seafarers is also registered in Brazil, making up 1,1 per cent of the workforce [22]. Wodak pointed to this geographical gap between north and south and a discrepancy in women's employment in the Nordic and the Mediterranean countries. According to Wodak, gender roles surprisingly differ because the countries of the South tend to be male-dominated, while the Scandinavian people have long ago established gender equality [23]. The rise of women seafarers in Eastern and Southern Africa was the subject of the research paper by Bhirugnath-Bhookhun and Kitada [24]. These scholars have noted a considerable improvement in female seafarers' careers given their managerial positions on board. Nevertheless, seafaring in this country is seen as challenging and there is a lack of support for women's careers at sea.

Media texts, journals and online platforms have significantly contributed to raising awareness about female and feminist issues in seafaring. The presence and media visibility of women in gendered professions in Arabian countries have drastically increased since the 1990s owing to digital technology. The news media is interactive, involves more women regardless of their social position. Egyptian women, for instance, have been very active in using cyberspace and blogs. In some Eastern countries and countries in the Balkans, the access to online communities is of particular importance. In these regions men were regarded as protectors and these cultures were described as male-centred. Women were in a shadow as politics in many transition countries was focused on internal political and national problems [25].

The third current closely the growing visibility of women in shipping is social media. We have noted that there is very little research on the role of media in the representation of women in the maritime community. However, digitalization allows a more convenient collection of available material at the disposal of discourse analysts. We assume that the mainstream media will confirm the vital role in reinforcing the image of women fighting for their place and constructing their identity [26]. Images of women in the uniform, at the helm of the ships, are being broadcast on national televisions as top news [21]. Notably, writing about women has focused on women's personal stories for a long time, while their collective public image has been underrepresented. The accessibility of media platforms allowed women to share their experiences and connect globally.

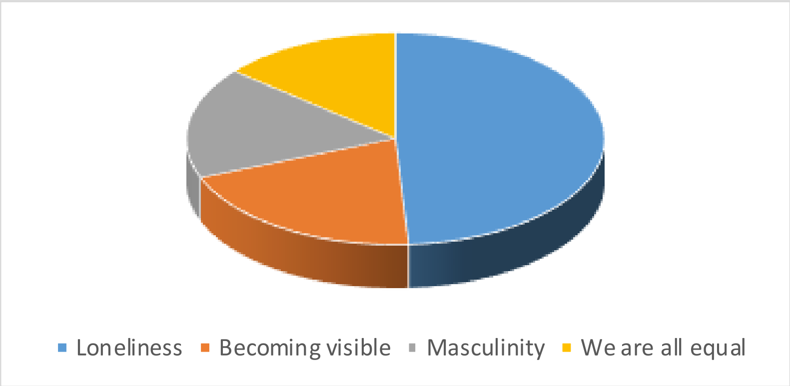
2. METHODOLOGY AND CORPUS

The corpus utilized in this paper comprises online interviews and reports about women seafarers published over ten years (from 2010 to 2020). To compile a corpus, we searched newspaper articles using the search terms 'women seafarers'. Overall, a total of 50 texts were analysed, making up 72, 591 words. The corpus was not limited to a particular geographic region as the aim was to get insight into the current position of women seafarers on the global level. We retrieved the texts from recognised news portals, such as *The BBC, The Daily Mail, The Telegraph, The Guardian, The Times, Reuters, India Times, The Inquirer, NBC News,* and the most popular nautical websites *(Nautilus International, Maritime Women India times, Marine Insight*).

We imported the texts into the AntConc programme [27] to compile data regarding the frequency, word lists and concordance of the target words. However, the paper combines qualitative and quantitative analysis. In establishing the main concepts in the article, we were also led by intuition in choosing which linguistic level or rhetorical features should be explored. The pragmatic or socio-cognitive analysis required the knowledge of the relevant literature resources, a specific maritime context, gender studies, and current institutional regulations dealing with women seafarers. That is why we applied a qualitative or content-based approach based on the socio-cognitive model [3]. On the one side, we are aware that we collected a corpus consisting of digital data, which might undermine data reliability and authenticity. On the other, the established concepts might be applied in exploring specific sea-related cultures worldwide.

3. ANALYSIS

This part of the paper presents qualitative analysis of the collected texts. After the texts were carefully read, we established the four prevalent concepts related to women's position in seafaring.



Graph 1 Prevalent concepts in the corpus about women seafarers

In Graph 1, we present the four main concepts: 'Loneliness', 'Becoming visible', 'Masculinity', and 'We are all equal'. The 'movement' from 'Loneliness' to the 'We are all equal' concept has lasted for years. These changes are interwoven with social trends which affected hyper-masculine professional communities and will be further elaborated throughout the paper.

3.1. Loneliness

The first prevalent concept in the texts highlighted women's solitude. Thus, the first group of search words included the ordinal adjectives *first*, *second*, *third,* the noun *handful* expressing quantity or number, and the adjective *lone*. These discourse exponents are shown in Table 1.

Table 1 Discourse exponents of the 'Loneliness' concept

The concept	Discourse markers
Loneliness	Ordinal adjectives First woman (41) First female (71) First Irish (1) First Indian (4) First African-American (1) First Canadian (3) First Filipino woman (3) First female captain (32) First ever (5) First time ever (2) First woman to sail (4) The second (45) Cardinal adjectives Two women (5) Three women (7) three female (4) Adjectives lone (11) sole (1) The only female (13) Only woman (7) Only female /15) 'historic' Historic (moment) (1), historic (voyage) (2), historic (journey) (3), historic (news)2, historic (achievement) (2) The verb "meet" Meet (12)

The ordinal *first* occurs in 335 instances, of which 45 examples are found in the news headlines: "Australasia's *first* female cruise ship captain joins the Pacific Pearl", "*The first* female navy commander leaves ship and affair claim". Other examples of the woman's loneliness in the prevalent masculine community are *first and only, first-ever, first woman, first female,* and *the first woman to command*. Notably, the country that a woman seafarer comes from is highlighted in a headline. This is particularly indicative of women seafarers coming from those countries where institutional regulations have banned women from sailing (*first Indian, first Filipino woman, first African*). Furthermore, the concept of woman's loneliness in a male-dominated work environment is found in the phrases describing women as 'single', 'alone' and 'only' in 'man's territory'. Such discursive practice aims to achieve interdiscursive context [28].

"Being the only woman didn't bother her, but it did bother others at times" (irishtimes.com, November 2018)

"I want the day to come when women will not feel *alone* and uncomfortable in the room. I remember that feeling in many of my roles, and I want to change that for other women. And I have the opportunity to do that in my position" (Telegraph, March, 2020).

The concept of loneliness is found in the use of the verb *meet* in headlines. The verb *meet* is utilized as a rhetorical strategy aimed to draw the reader's attention. We identified twelve examples, some of which are shown in Table 2.

Table 2 The verb *meet* in headlines

Meet Kenya's first female marine pilot (standardmedia; October 2014)
Meet Ireland's first female master mariner (irishtimes, November 2018)
Meet Maritime Pilot, Captain Sherri Hickman (maritime executive, May 2018)
Meet Lucinda Krige, South Africa's first female marine engineer (83degreesmedia, July 2019)
Meet The all-female cruise crew who made history on International Women's Day (Telegraph,March 2020)

Number *two* appears in twelve examples in the corpus. It suggests that the shipping industry was moving slowly as far as women seafarers' employment is concerned.

"These *two* young women are making waves in the country's environmental community, not just for their passion, but because of the barriers they are breaking as two of the very few women working in the marine preservation sector, particularly scuba-diving, in Vietnam" (tuoitrenews.vn, February, 2019).

"Defence Secretary Philip Hammond hailed their huge personal achievement and said it was a historic moment for the Royal Navy and our armed forces" (*BBC*, May 2014).

The search of the phrase 'first women in shipping' generated many texts featuring women seafarers as breaking news in Africa, India, Italy, France, the United States, the Netherlands, Australasia, China, Russia, Australia, New Zealand, Canada, and the Philippines. As said, social media enabled globalization and better connectivity among women in the public sphere. National boundaries blurred in computer-mediated surroundings [5]. Women have become connected and open to new trends in a globalized world. As Lazar points out, it is about time to eliminate cultural assumptions of 'warm and attentive Asian' women, 'liberal American women', 'Hispanic women constrained by their men' [31].

"Following in the footsteps of Russians, Polish and American women, Indian women are increasingly taking up sailing jobs, once thought to be a male preserve" (The Economic Times, August 2010).

It is noteworthy that female empowerment is given a specific name in some parts of the world. For example, the first female officers' enrolment in the Indian Navy is called 'victory for Nari shakti' (woman power). The growing number of women on naval ships, warships, and submarines is a remarkable advantage for the Indian nation. This also means that the living quarters have been accommodated to include women.

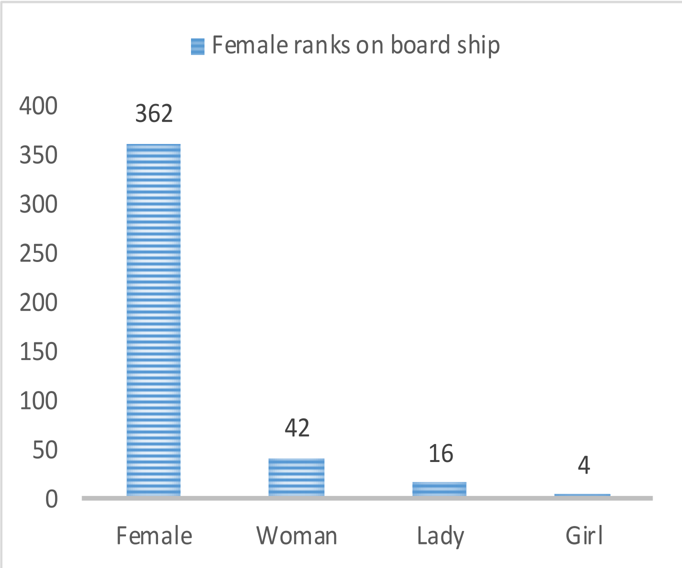
"Definitely yes. Nowadays all the warships coming into the Indian Navy, have different provisions and different rooms for lady officers. In the next few years, lady officers will go onboard ships" (shethepeople.tv, December 2017).

3.2. Becoming visible

The second concept, named 'Becoming visible', suggests that women have become more inclusive in the maritime sector. In this part, we explore feminine designations on board. The quantitative data to support this concept were obtained by searching for gendered modifiers *female/woman/lady/girl*. As already mentioned, changes in publications' language policy came with social settings changes, including non-sexist language and 'verbal hygiene practices' [11]. In addition, calling women by male occupations in male-exclusive professions (pilot, lawyer, professor, doctor, and police officer) was associated with men's dominance in discourse [2].

Our findings show that the most deployed terms denoting ranks such as captain, master, officer, engineer, and pilot are unmarked and refer to men and women. The modifier 'female' occurs 362 times, whereas 'woman' ('women') occurs 42 times. 'Lady' is found in six instances, while 'girl' occurs in four.

In our corpus, the most frequent modifier 'female' collocates with a *captain* in 37 examples, of which it appears in *the first female captain* in 13 instances. The examples in descending order are *female officers* (40), *female cadets* (26), *female seafarers* (11), *female submariners* (5), and *female engineers* (3). This implies that the 'female' is preferred to other modifiers (Graph 2) and mostly occurs in the phrase 'female officers'. As for the 'woman' as a modifier, we found only one example with a woman captain, and 32 examples with women/woman officers. What follows are women seafarers (24), women submariners (4), and women pilots (4). We haven't found any example of a woman cadet. *Lady captain* was found in one example, whereas we found three instances of *lady officers* (3) and *lady cadet (2)*. The noun *girl* as a modifier appeared in four instances in that of a 'girl cadet'. The modifier 'girl' implies a less serious role or a newcomer in the field. Sunderland observes that 'girl' can be an instance of a woman's success or girls 'in the lead – but for the first time' [12]. Therefore, we assume that modifiers *female* and *woman* in our corpus refer to higher ranks – female captains and officers.



Graph 2 The use of *female/woman/lady/girl* for female ranks

On the other hand, the modifiers 'lady' and 'girl' are scarce in our corpus and denote a lower ranking. We may assume that these modifiers indicate less challenging jobs and impart a frivolous tone. Litosseliti [32] noticed that the use of so-called 'gratuitous modifiers' such as 'woman doctor' or 'lady doctor' weakens the term's primary function: instead of emphasizing the female sex, they rather undermine a woman's prestige.

The following concept questions the fight against gender stereotypes depicting women as physically and mentally weak and more likely to be involved in sexual scandals.

3.3. Masculinity

The third concept of 'Masculinity' draws on the linguistic evidence that ship is a specific masculine microcosm. Our results are based on the quantitative analysis retrieved from the frequency of the search terms *man, man's,* and *male* [27]. Our findings, presented in descending order show that 'male' appeared 110 times with '*male-dominated*' in 33 examples (Figure 1). What follows are '*all-male community*' (5 examples), '*male-bastion*' (three times) and one example with *'male-territory'* and '*male-only*'.

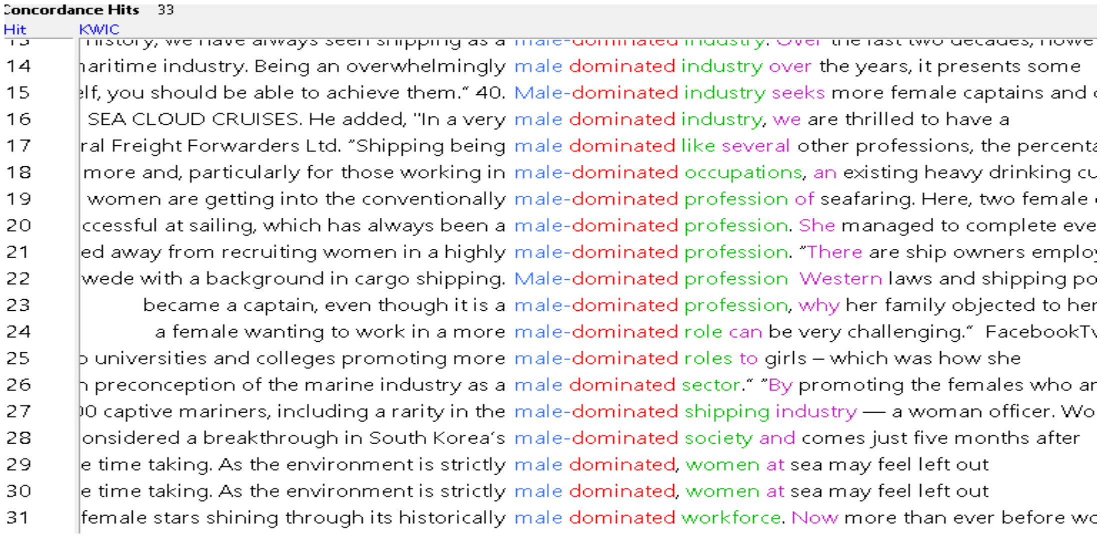


Figure 1 Screenshot of the concordance line 'male-dominated' in the corpus

"As Sarah Breton makes British history with P&O this week, she reveals how a career that began as a teenager on the high seas has taken her to the top in a *male-dominated world*" (The Telegraph, 21 April 2010).

"In a country that has one of the narrowest gender gaps in the world, the seafaring industry remains lamentably *male-dominated*" (The Telegraph, 8 March 2015).

The search of the possessive use of 'man's/men's' elicited 43 examples. The linguistic exponents of the ship as a masculine arena are *man's world* (15), *man's power* (10), *man's domination* (5), *man's arena* (4), *man's job* (3), *the old man's land* (2), *men's old boy's network* (1), *men's network* (1) and *men's community* (2).

"This is a *man's world*, says Bosun Evalisto Shipo. Since the beginning, it's been a *man's world*. If your leadership is not appropriate for the crew, you will not earn their respect" (BBC News, 6 August 2010).

As a result, in some patriarchal societies, 'man's dominance' is transferred from land to the sea, and women are in the 'possession' of their masters at sea. Patriarchal perspectives about femininity constituted and distorted women's actual capacities [33].

"When we arrived, one said, we were told that the captain is our god. He can marry you, baptise you and even bury you without anybody's permission. We were told that the sea is no man's land and that what happens at sea stays at sea" (The Telegraph, 6 September 2013).

"On land, women can better balance families and careers. At sea, the prospects of months away from home, deep skepticism among male mariners and unawareness of career opportunities have preserved a man's world" (NBC News, 10 June 2014).

In the Philippines, women have a vital role in the household. It is estimated that Filipinos make the most significant crew and participate with the estimated 1, 6 million seafarers. However, the corpus analysis revealed that the world only recently met the first female Filipino captain (2019). Moreover, we documented that in the Philippines and Singapore women's connection with home and household chores is called by a specific term. Any forbidden activity is expressed with a taboo word.

"Almost always, they are still considered *pambahay* or good only for the home. Those who dare defy or challenge such sexist views are often discriminated against and isolated by male seafarers" (The Times, March 2016).

These facts show that the prevalence of patriarchal control presents the main impediment for women seafarers. "This sad reality shows that the empowerment of women seafarers must start at home. This means that even if the country produces many women captains and chief engineers, it would be meaningless if they end up as victims of domestic violence and patriarchal control at home" [34].

"On one ship, I was told that girls were not allowed to walk through the engine room because it's *pantang* said Col Goh, 42, using the Malay word for 'taboo'" (straitstimes, May, 2017).

Of the many reasons favouring the notion that seafaring is masculine-oriented, one is attributable to accommodation. Namely, facilities on board, particularly on submarines, are not woman-friendly, bearing in mind the life with mixed crew and the factors such as women's health.

"There are also many practical problems with accommodating women. On the older Trafalgar class submarines men still 'hot bunk'– sharing a bed with someone on a different shift. (…) Enforcing the Royal's Navy 'no touching rule' for mixed crews might be harder, given the limited confines of the submarine" (BBC News, 8 December 2011).

Women working on shore are more likely than are men to be involved in sexual affairs [35]. Such biological determinism is characterized for workplaces that were originally classified as masculine (army, navy, air force). Thus, media stories about sexual misconduct (with women as main actors) attract media attention. In the following example, a single woman, using a metonymy as a rhetorical pattern (when a part is taken as a whole), represents all future generations of women seafarers.

"And as an intense military investigation is launched into Cdr West's conduct, the former head of the Navy said that if the claims were true, the trailblazing commander would have let down all female officers – and provided fuel for those who argue against women being on active service" (*Daily Mail,* 26 July 2014).

It is worth mentioning that the recent rise of the #metoo movement has also brought the question of sexual and gender harassment, together with the lack of institutional regulations tackling this problem [35,36, 37]. The #metoo campaign gathered women worldwide to speak about gender-related violence, particularly in the specific workplace setting. Motivated by the #metoo initiative, more than one thousand Swedish women formed the Facebook group under the hashtag #l€attaankar (Swedish for anchors aweigh). We have found more than twenty female organizations and associations on Twitter and Instagram dealing with women empowerment in the maritime sector such as #womenonboard, #womeninshipping #shefarers, #womensafarers, etc.

3.4. We are all equal

The concept named 'We are all equal' shows that women think of their colleagues as 'brothers', and 'family members'. Alternatively, women's male colleagues talk about women as sisters, mothers, and daughters. Our findings in this part of the paper are based on the random semantic exponents elicited by associating linguistic data with the pragmatic (maritime) setting. We conclude that women have achieved a balance in the male-dominated work environment aboard ship. Some women do not wish to be called by female titles, and they have a somewhat masculine attitude towards their jobs.

"Equipped with the same knowledge and skills as men, female marine officers like Arrojado forget about fashion and makeup and wear uniforms "like one of the boys." They perform all duties that their male colleagues do, including dropping the heavy anchor chain, carrying a heavy load and mixing chemicals to prevent ship pipes from rusting" (Inquirer, March 2016).

Moreover, we also found instances that women talk about their fellow seafarers as if they were their brothers. They call them 'silly boys', 'brothers', 'pals'.

"Hazel stresses the importance of keeping your professional life strictly professional, "there are many boys; you have to be careful to work hard and don't get lost" (offshore-energy.biz, March 2017).

"At the end of the day, I had a lot of big brothers" (Sunday Times, November 2019).

We have already noted that women do not mind if they are called by masculine titles, even though patronizing can sign sexist discourse [38]. They are aware that wording does not matter and that some female forms imply sexist connotation. This could happen if we tried to make female forms for the helmsman, sailorman, seaman motorman, and watchman, that is, if we replaced 'man' with 'woman' [39].

"The vernacular is to call the captain 'the old man', and we would call her 'old man', and it was not an issue, Collins said. Maintaining maritime tradition was more important than gender identity" (The Telegraph, 12 January 2001).

Nevertheless, the term 'Madam', the female equivalent of the title 'Sir', is not used to address female officers in the army and navy [40]. For example, in helm orders on ships, a sailor has to repeat captain's steering order. In such cases, the term 'Sir' rather than 'Madam' is used to confirm that the order is understood: "Yes, Sir, I am keeping my present course". This wording should not be regarded as an exercise of man's power over women in language. Instead, it shows us that language is dynamic, dependent on the context. Therefore, power and solidarity may be on a single continuum or axis, not on the opposing ones [9].

The women belonging to 'we are all equal' concept in our paper may be said to steer a safe route in the fight for their place in a profession stereotypically defined as masculine. These women minimize the notion of femininity, which is attributed to women [41]. Feeling 'like one of the boys', 'a part of a team', and thinking of the males as 'brothers or 'my men', are examples of integration into (male) reality on modern ships. Femininity might come under attack, but a masculine model is considered a professional model, compared to a feminine or 'feminized' discourse [42].

"Females on my crew, they really and truly just want to be seen as submariners. That's it" (Csmonitor, March 2018).

However, we have also found that sometimes women act in an authoritarian way to prove themselves as able leaders [2].

"I had to learn to ignore the insults and become a figure of authority. The only way was to be 110 percent professional and make sure I was capable of doing every job I asked 'my men' to do" (The Times, 4 September 2000).

4. CONCLUSION

The four concepts established in our paper reflect the socio-cognitive relationship between discourse and context in a maritime sector. The male-female relationship on board is complex and socially shaped, with all social experiences, activities, norms, and values in mind [2]. Also, the changes in the professional roles are linked to pursuance of the Western sociocultural pattern [4] supporting women to participate in all social spheres and functions in the leading positions.

Drawing on gender, discourse, and power theories helped us examine the relationship between gender and language considering discursive manifestations of gender empowerment and status. Keeping in mind the above socio-cognitive dimensions of discourse, we established the most prevalent concepts related to women seafarers: 'Loneliness', 'Becoming visible', 'Masculinity', and 'We are all equal'.

The first concept 'Loneliness' explores the occurrence of 'first', 'second', 'third', 'only', 'single', 'lone', 'handful' and 'loneliness', indicative that women are seen as 'a novelty' on board. In news reporting, headlines such as 'the first/second/only women on board…' present an effective rhetorical strategy to refer to the scarcity of women in seafaring. To prove the second concept 'Becoming visible', we conducted a quantitative analysis with the search words 'female', 'woman', 'lady' and 'girl' applied to name female professions in the 'all-male world'. Also, we found that women on board were often called by a different name or a taboo word in patriarchal countries. The phrases referring to the third concept or 'Masculinity' include the nouns 'male' and 'man' as in 'male-dominated', 'man's network', 'all-male community', 'male bastion'. In these texts, women were portrayed as weaker for biological and physical reasons. Moreover, the notion has been put forward that women cannot live in confined spaces, particularly on navy ships and on submarines, and that they should not share public areas with men.

The fourth concept, referred to as 'We are all equal' showed that women agreed to be called by masculine titles and that they utilized language attributable to man's talk (e.g. 'brothers, 'my men', 'pals'). Thus, some women mitigated gender differences on board utilizing masculine verbal discourse patterns and masculine physical behaviour.

The conclusion drawn from this paper's is that women aren't yet equal to men in the maritime work setting. It seems that the masculine-feminine polarization reached its highest point a decade ago, and current perspectives are seen as sailing towards calming seas. Moreover, our findings show that women succeed in acquiring positions in the top hierarchy on board. However, a whole set of extralinguistic issues should be taken into account (the company policy, gender restrictions, culture, laws). Social media go hand in hand with this trend, particularly with the rise of gender-related movements which mobilized and united women in all professions globally—newspapers and media are an essential intermediary in 'doing gender' [43]. Social networks, blogs, Facebook and Instagram significantly promote organisations fighting for women's rights, such as WISTA [44]. In light of the above research, we strongly believe that the empirical results obtained in this paper will inspire other scholars to explore how discourse reveals different perceptions about men and women in traditionally masculine work occupations with a particular focus on differences in cultural values.

REFERENCES

[1] Dževerdanović-Pejović M. (2017) Linguistic facts a reflection of changes in seafaring: Is ship still a 'she'. *The Mariner's Mirror*. Vol. 103. No. 3, pp.313–322

[2] Van Dijk, T. A. (2008) *Discourse and Context: A Sociocognitive Approach*. Cambridge University Press. New York

[3] Van Dijk, T. A. (2009) Society and Discourse: How Social Contexts Influence Text and Talk. Cambridge University Press, New York

[4] Van Dijk, T. A. (2014) *Discourse and Knowledge: A Sociocognitive Approach*. Cambridge University Press, New York

[5] Koller, V., Wodak R. (2008) *Handbook of Communication in the Public Sphere*. Walter de Gruyter, Berlin.

[6] Siegfried J. (2016) Discourse and knowledge: theoretical and methodological aspects of a critical discourse and dispositive analysis. In *Methods of Critical Discourse* Analysis, Wodak, R, Meyer M. (eds), pp. 32–63. Sage Publications, London

[7] Lakoff, R. (1973) Language and Woman's Place. *Language in Society*. Vol. 2, No. 1, pp. 45–80.

[8] Lakoff, R. (2000) *Language War*. University of California Press, Berkeley

[9] Tannen, D. (1990) *You Just Don't Understand: Women and Men in Conversation*. Random House, New York

[10] Cameron, D. (2003) Gender Issues in Language Change. *Annual Review of Applied Linguistics*. Vol. 23, pp. 187–221

[11] Cameron, D. (2012) *Verbal Hygiene*. Routledge, London.

[12] Sunderland, J. (2006) *Language and Gender – An Advanced Resource Book*. Routledge Applied Linguistics. London, p.42

[13] Hibberd A., Woolcock N. (2002) Lloyd's List sinks the tradition of calling ships "she"'. Accessed July 2018. https://www.telegraph.co.uk/news/uknews/1388373/Lloyds-List-sinks-the-tradition-of-calling-ships-she.html

[14] Gioldin, C. (2006) The Quiet Revolution That Transformed Women's Employment, Education, and Family. *The American Economic Review*. Vol. 96, No. 2, pp. 1–21. Accessed September 2020, http://www.jstor.org/stable/30034606

[15] Coughlin, J. H., Thomas R. (2002) *The Rise of Women Entrepreneurs: People, Processes and Global Trends*. Quorum Books, London

[16] Wood, T. J. (1994) Gendered Media: The Influence of Media on Views of Gender. *Gendered Lives: Communication, Gender and Culture*, pp. 231–244

[17] Mackay, F. (2015) Radical Feminism Feminist Activism in Movement. Palgrave Macmillan, London.

[18] Women in shipping: pushing for gender diversity. Accessed August 2020, https://www.ship-tecnology.com /features/featurewomen-in-shipping-pushing-for-gender-diversihty-5907538/

[19] Kitada, M. (2021) Women Seafarers: An Analysis of Barriers to Their Employment. In *The World of the Seafarer* , Gekara V. O, Sampson H. (eds.). *WMU Studies in Maritime Affairs*, Vol. 9, pp. 65-76, Springer, Doi:10.1007/978-3-030-49825-2_6

[20] Nicholson, N., West M. (1988) *Managerial job change: men and women in transition*. Cambridge University Press

[21] Aggrey, H. A. Women in the maritime industry: a review of female participation and their role in Maritime Education and Training in the 21st century. World Maritime University Dissertations. Malmo, Sweden. Accessed November 2020, https://core.ac.uk/download/pdf/217237093.pdf

[22] International Labour Office (2003) *Women Seafarers: Global Employment Policies and Practices*, International Labour Organization

[23] Wodak R. (2005) Gender Mainstreaming and the European Union: Interdisciplinarity, Gender Studies and CDA. In *Feminist Critical Discourse Analysis*, Michelle M. (ed), pp. 90–113. Palgrave Macmillan, London

[24] Bhirugnath-Bhookhun, M., Kitada M. (2017) Lost in success: women's maritime careers in Eastern and Southern Africa. *Palgrave Communications* 3, 17023. doi: 10.1057/palcomms.2017.23

[25] Isanović, A. (2006) Media Discourse as a Male Domain: Gender Representation in the Daily Newspapers of Bosnia and Herzegovina, Croatia and Serbia. In *Stereotyping: Representation of Women in Print Media in South East Europe*, Bamburać M. N., Jusić T., Isanović A. (eds.), pp. 49–84, Sarajevo Mediacentar, Sarajevo

[26] Gauntlett, D. (2008) *Media, Gender and Identity: An Introduction*. Routledge, London.

[27] Lawrence, A. (2014) AntConc 3.2 [Computer Software], Waseda University, http://www.laurenceanthony.net/

[28] Bhatia, VK. (2017). *Critical Genre Analysis: Investigating interdiscursive performance in professional practice*. Routledge, London

[29] Magramo, M. M., Geneva E. (2012) Women Seafarers: Solution to Shortage of Competent Officers? *International Journal on Marine Navigation and Transport and Safety of Sea Transportation*, Vol. 6, No.3 pp. 397–400

[30] Miller, L., Kavanagh J., Lytell M. C., Jennings K., Craig M. (2012) *The Extent of Restrictions on the Service of Active-Component Military Women*. RAND Corporations, Pittsburgh

[31] Lazar, M. M. (2008) "Language, communication and the public sphere", in *Handbook of Communication in the Public Sphere*, Koller, V., Wodak R. (eds.), pp. 89-113, Walter de Gruyter, Berlin

[32] Litosseliti, L. (2006) *Gender and Language: Theory and Practice*. Routledge, London, p.14

[33] Pilcher, J, Whelehan I. (2004) *Fifty Concepts in Gender Studies*. Sage Publications, London

[34] Tangi, L. P. (2016) Empowering Filipino Women Seafarers in the Maritime Sector. *Public Policy* Vol. 15 No.2, pp. 162–198

[35] Carballo P. L., Kitada M. (2020) Sexual harassment and women seafarers: The role of laws and policies to ensure occupational safety & health. *Marine Policy* Vol. 117, doi: 10.1016/j.marpol.2020.103938

[36] Maaranen, A., Tienari J. (2020) Social media and hyper-masculine work cultures. *Gender, Work& Organization*, Vol. 27, pp. 1127-1144. Doi:10.1111/gwao.12450

[37] De Benedictis S., Orgad S., Rottenberg C. (2019) #MeToo, popular feminism and the news: A content analysis of UK newspaper coverage. *European Journal of Cultural Studies* Vol. 22, No. 5, pp. 718–738.

[38] Sunderland, J. (2004) *Gendered Discourses*, Palgrave Macmillan, New York

[39] Dževerdanović-Pejović M. (2020) Linguistic facts a reflection of changes in seafaring: Is ship still a 'she'?. *Transactions on Maritime Sciences*, Vol. 2, pp.350–357

[40] Romaine, S. (1999) *Communicating Gender*. Lawrence Erlbaum Associates, New York

[41] Kitada, M. (2013) Code of Behaviour at Sea: Women Seafarers' Shipboard Identity Management. *WMU Journal of Maritime Affairs*. Vol. 12, No. 2, pp. 213–227

[42] Holmes, J., Stubbe M. (2015) *Power and Politeness in the Workplace: A Sociolinguistic Analysis of Talk at Work*. Routledge London and New York, p. 42

[43] Bierbach, C. (1997) Is Spain different? Observations on male–female communicative styles in a Spanish group discussion. In Kotthoff H., Wodak R., (eds.). *Communicating Gender in Context*. John Benjamins Publishing Company, Amsterdam, pp. 107–138

[44] WISTA international (2019) Website: https://wistainternational.com. Accessed 12 January 2020, https://wistainternational.com/

ENERGY OPTIMIZATION OF SERIES HYBRID SYSTEMS FOR ELECTRIC TRANSPORT

Sergey German-Galkin
Department of Mechatronics and Electrotechnology, Maritime University
Szczecin, Poland
E-mail: s.german-galkin@am.szczecin.pl

Dariusz Tarnapowicz
Department of Mechatronics and Electrotechnology, Maritime University
Szczecin, Poland
E-mail: d.tarnapowicz@am.szczecin.pl

UDK 62-523
681.5

Summary

The article considers a hybrid mechatronic system for ship's propulsion, consisting of two installations (the same type) connected by a DC link with an energy storage unit. In the literature, they are called sequential structure. Each installation includes a permanent magnet synchronous motor (PMSM) and an active semiconductor converter (ASC). One installation produces electricity and is a generator. The second unit converts electrical energy into mechanical energy and is an electric drive. Thanks to the use of modern technologies, there are unused resources to increase energy efficiency in the conversion of electromechanical energy in such systems. In this study is considered methods for controlling the generator and electric drive aimed at optimizing the energy performance of the hybrid mechatronic system. The study considers and examines methods for controlling the generator and electric drive (AMS) aimed at optimizing the energy performance of the hybrid mechatronic system. Electromagnetic and energy properties of the system are examined. The idea of energy optimization (proposed in the article) can also be used in other mechatronic systems, e. g. in cars.

Keywords: Series Hybrid Systems, Energy Optimization; Control of the Active Converter

1. INTRODUCTION

The popularity of electric drives in various means of transport (land, water or air) increases not only due to ecological reasons, but also because of its advantages over diesel-mechanical drive. The main advantages of the electric drive (also diesel-electric) are: reduced fuel costs, excellent torque and speed characteristics, (including fast dynamics), as well as reduced vibrations.

Examples of such systems are, in particular, mechatronic systems in autonomous electric transport. A universal solution that ensures all working conditions and improves the energy performance of transport systems is realized through the use of active semiconductor converters (ASC) [1].

In the case of the emergency of new technologies, there are many different approaches to design hybrid systems for means of transport with electric drive. The article proposes an analysis of the system in a series hybrid design [2-5] (Figure 1).

Electric machines used in the analyzed system are synchronous machines with permanent magnets (generator (PMSG) - Permanent Magnet Synchronous Generator and electric motor drive (PMSM) - Permanent Magnet Synchronous Motor). The use of such machines results from the advantages of these machines – i. e. high efficiency, especially in the case of underload generator, mainly caused by the elimination of excitation losses, high operational reliability and simple construction due to the lack of windings on the rotor and the lack of exciter, high power density and low vibration level [1, 6].

The article presents mathematical models of subsystems and the applied ASC control strategy in order to optimize the energy performance of a hybrid mechatronic system.

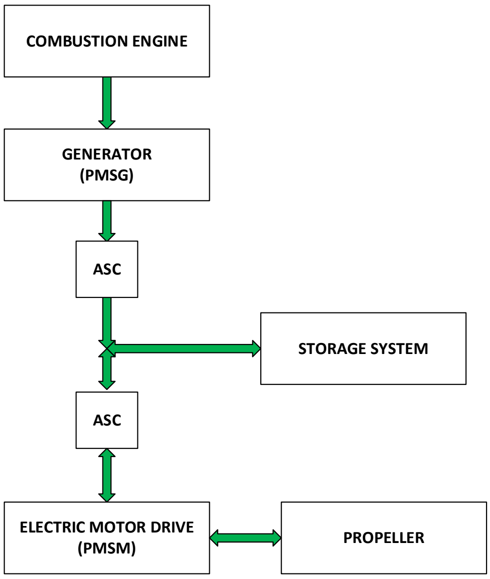


Figure 1 Typical Series Hybrid Architecture

2. EQUIVALENT CIRCUIT OF THE SERIES HYBRID SYSTEM

The structure of the Vehicle Serial Hybrid Mechatronic System (SHMS), presented in Figure 1, contains three power sources. The first source includes an internal combustion engine (CE), PSMG and ASC – i. e. an Active Rectifier (AR) with the Active Rectifier Control System (ARCS). The second source is an electricity store (batter with a supercapacitor). The third source is PMSM with ASC, which is an active converter (AC) with the ACCS (Active Converter Control System). It enables the power flow in both directions. A substitute scheme, for analysis of SHMS, is shown in Figure 2, where the following values are marked:

ω_{mg} -rotational speed of the PMSG shaft,

$\bar{E}_{GS}$ - EFM of PMSG,

$\bar{I}_{GS}$ - PMSG armature current,

$\bar{U}_{AR}$ - voltage on the AC side of the AR,

r_g, x_g - resistance and reactance of the PMSG,

P_{GS} Q_{GS} - active and reactive power in the PMSG-AR system,

$\bar{I}_{D\_AR}$ - current in the AR – DC side,

ω_m - rotational speed of the PMSM synchronous shaft,

$\bar{E}_{EM}$ - EFM electromotive force of PMSM,

$\bar{I}_{EM}$ - PMSM armature current,

$\bar{U}_{AC}$ - alternating voltage (AC),

r_m, x_m - resistance and reactance of the PMSM,

P_{EM} - active power in the AC-PMSM system,

Q_{EM} - reactive power in the AC-PMSM system,

$\bar{I}_{D\_AC}$ - current in the AC – DC side,

P_{dc} - active power in the DC circuit.

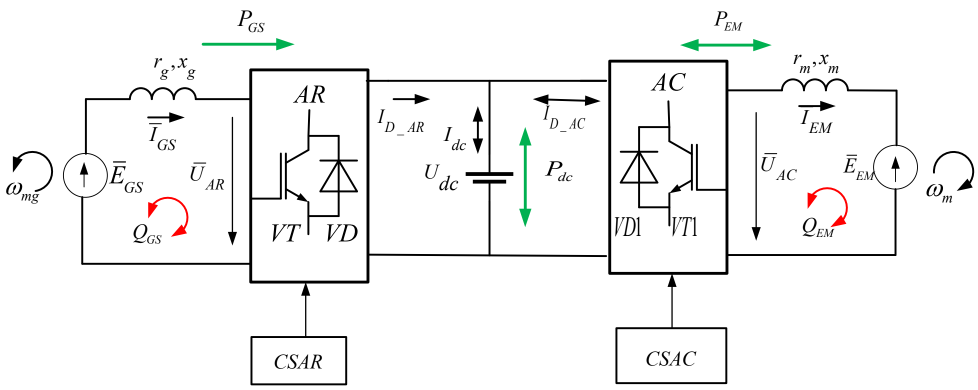


Figure 2 Equivalent Circuit of SHMS

Only active power P_{dc} is transferred in the DC circuit. In AC circuits, there is an active power transfer P_{GS}, P_{EM} and reactive power circuit. Q_{GS}, Q_{EM} . Active powers are rigidly coupled, and reactive powers depend on the method of controlling the AR and AC active converters. Reactive powers are decoupled and they can be controlled independently of each other.

Analytical and model studies of SHMS energy characteristics are performed on the basis of the analysis of electromagnetic processes in quasi-stationary modes [7]. The electromagnetic processes in the system are studied using an equivalent circuit diagram (Figure 2), taking into account the theoretical ones developed [8-11].

3. MATHEMATICAL DESCRIPTION AND EXAMINATION OF THE SHMS SYSTEM

3.1. Mathematical description of the PMSG-AR system of the SHMS electric drive

In the considered substitute scheme (Figure 2), on the AC side of the AR, the voltage source is connected in series with the EFM PMSG through the stator windings of the PMSG $\overline{U}_{AR}$.

The mathematical description of the PMSG-AR generating set of the SHMS system is carried out in a coordinate system rotating synchronously with the generator rotor using the method [12] and the fundamental harmonic method [8]. This mathematical description takes the following form:

$$\overline{E}_{GS}(t) = \overline{U}_{AR}(t) + L_g \frac{d\overline{I}_{GS}(t)}{dt} + r_g \overline{I}_{GS}(t) + jx_g \overline{I}_{GS}(t). \tag{1}$$

where:

$\overline{E}_{GS} = p\omega_{mg}\psi_0 = \omega\psi_0$ - spatial vector of EMF voltages on the stator's windings of the PMSG,

$\omega = p\omega_{mg}$ - angular frequency of AR voltage,

p – number of pole pairs.

Investigation this system requires the use of vector diagrams to study energy properties of the "PMSG-AR" system. When constructing the vector diagram according to the equation (1), it should be taken into account that the AR is controlled by the rotor position sensor (RPS). Therefore, electromagnetic processes in the generator are rigidly related to the rotational coordinates (*d*, *q*), which (in turn) are determined by the generator's structure. In this case, the flux vector $\overline{\varphi}_0$ coincides with the RPS null state and is oriented in the longitudinal axis (*d*) of the coordinate system rotating at synchronous speed. Simultaneously, the EMF of rotation ($\overline{E}_{GS} = j\overline{\varphi}_0 p\omega_m$) is 90 degrees ahead of flux $\overline{\varphi}_0$ and it will be directed along the imaginary (transverse) axis - *q*. Electromagnetic processes in the AC circuit (AR), related to the voltage and current of the active rectifier, are considered in the rotational *x*, *y* coordinate system, which (in general) do not coincide with the *d*, *q* axis. In the rotational coordinate system (*d* is the real axis) and (*q* is the imaginary axis), when the real axis is set in line with the machine's excitation flux vector, equation (1) - in the *d, q* axes - takes the following form:

$$\begin{aligned} 0 &= U_d(t) + L_g \frac{dI_d(t)}{dt} + r_g I_d(t) - x_g I_q(t), \\ E_{GS} &= U_q(t) + L_g \frac{dI_q(t)}{dt} + r_g I_q(t) + x_g I_d(t). \end{aligned} \tag{2}$$

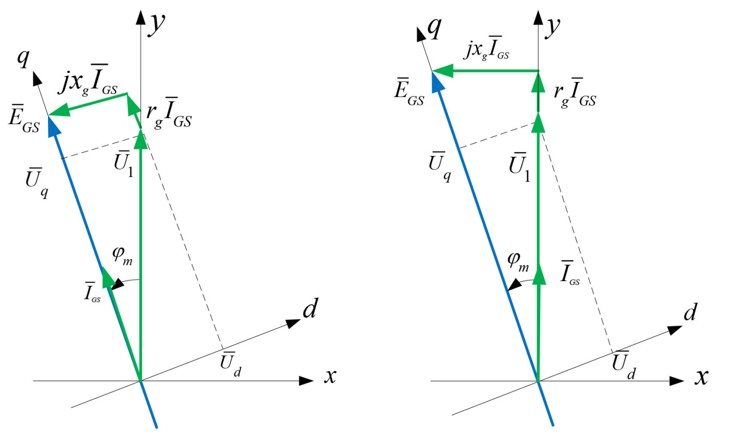
In the steady state, the vector system of equations (1) is converted to the form:

$$\bar{E}_{GS} = \bar{U}_{AR}(t) + r_g \bar{I}_{GS} + jx_g \bar{I}_{GS} \tag{3}$$

The scalar system of equations (2) in the steady state is presented as:

$$\begin{aligned} 0 &= U_d + r_g I_d - x_g I_q, \\ E_{GS} &= U_q + r_g I_q + x_g I_d. \end{aligned} \tag{4}$$

Vector diagrams constructed with the use of equation (3) are presented in Fig. 3a,b for two methods of controlling the active rectifier. In the first method, the active rectifier is controlled only along one (transverse) q axis. This control method is often referred to in the literature as field-oriented control (FOC) by analogy to asynchronous control systems. The vector diagram for this control method is presented in Fig. 3a In the second method that has been described in detail and analyzed in, control signals are set in an appropriate way to ensure that there is a zero reactive current in the active rectifier. This method is called the optimal method, and the vector diagram corresponding to the optimal control method is presented in Figure 3b.



a) b)

Figure 3 SHMS vector diagrams with different control methods in the PMSG-AR system, a – FOC, b – optimal control

3.2. Mathematical description of the AC-PMSM system of the SHMS electric drive

In the rotating coordinate system, the electromagnetic processes occurring in the SHMS drive are described by the following equation:

$$\bar{U}_{AC} = \bar{E}_{EM}(t) + L_m \frac{d\bar{I}_{EM}(t)}{dt} + r_m \bar{I}_{EM}(t) + jx_m \bar{I}_{EM}(t) \tag{5}$$

In the coordinate system (d is the real axis) and (q is the imaginary axis), when the real axis is aligned with the PMSM excitation flux vector, the equation $\bar{\varphi}_0$ (5) transforms into a system of scalar equations:

$$U_d(t) = L_m \frac{dI_d(t)}{dt} + r_m I_d(t) - x_m I_q(t),$$
$$U_q(t) = E_{EM} + L_m \frac{dI_q(t)}{dt} + r_m I_q(t) + x_m I_d(t). \qquad (6)$$

The equations of electromagnetic processes in the steady state result form (5, 6) and are indicated in the form:

$$\overline{U}_{AC} = \overline{E}_{EM} + r_m \overline{I}_{EM}(t) + jx_m \overline{I}_{EM} \qquad (7)$$

$$U_d = r_m I_d - x_m I_q,$$
$$U_q = E_{EM} + r_g I_q + x_g I_d. \qquad (8)$$

Vector diagrams constructed with the use of the equation (7) are shown in Fig. 4a, b for the FOC methods and optimal control of the active converter. The vector diagram for FOC is presented in Fig. 4, a. In the case of optimal control method, the vector diagram is presented in Fig. 4, b.

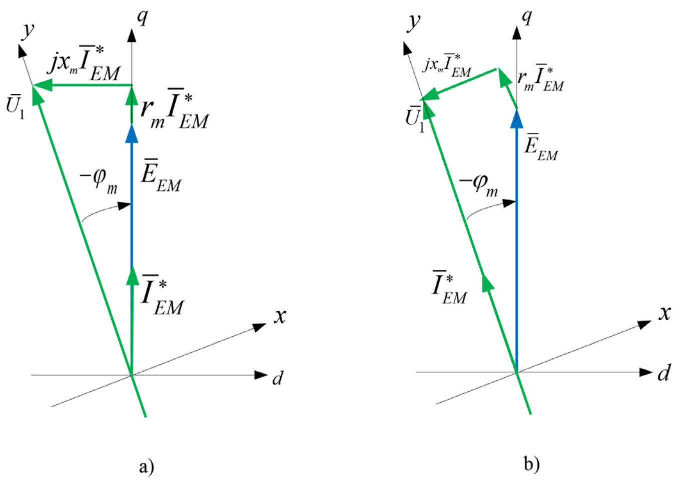


Figure 4 SHMS vector diagrams with different control methods in the AC-PMSM system, a – FOC, b – optimal control

The results of theoretical studies were verified by modeling the system in the Matlab-Smulink environment.

The tests are performed for SMHS, where the parameters of machines are presented in Table 1.

Table 1 Parameters of Machines

parameter	Nominal torque for continuous operation	Nominal speed	Armature winding resistance	Inductance of the armature winding	EMF	Number of pole pairs
unit	Nm	rad/s	W	H	Vs/rad	-
value	126	300	0.05	0.000635	0.192	4

4. MODEL EXAMINATION OF SHMS

The SHMS model examinations were carried out for the generating set and the electric drive with FOC and optimal control.

SHMS model (Figure 5) includes:

- Electric drive containing the ACCS control system Active Convertor and AC-PMSM power part;
- Generator set contain Control System Active Rectifier and PMSM-AR power part (Fig. 6).

This model enables to test quasi-steady and quasi-dynamic electromagnetic and energy processes in SHMS.

The current and rotational speed of the SHMS generator set are shaped by the Control block (Fig. 6). The current of the PMSM drive is formed on the output of the PI controller, the set signal of which is the set rotational speed.

Hist_Control blocks are relay regulators that control the current in PMSG-AR and PMSM-AC systems.

Electromagnetic and energy processes in the hybrid mechatronic system of the electric drive were simulated in the following operating modes:

1. When starting the electric drive with current (torque) limitation, when the object is moving and the PMSG is not working.
2. At constant speed of the object and constant speed of the combustion engine.
3. At constant speed of the object and constant rotational speed of the combustion engine
4. During deceleration of an object and then driving at a slower speed.

Switching between the above-mentioned modes takes place in a step-by-step manner. This enables the observation of transition states in SHMS. Modeling in SHMS was carried out in a system with the FOC control and optimal control – both in the generator set and in the electric drive.

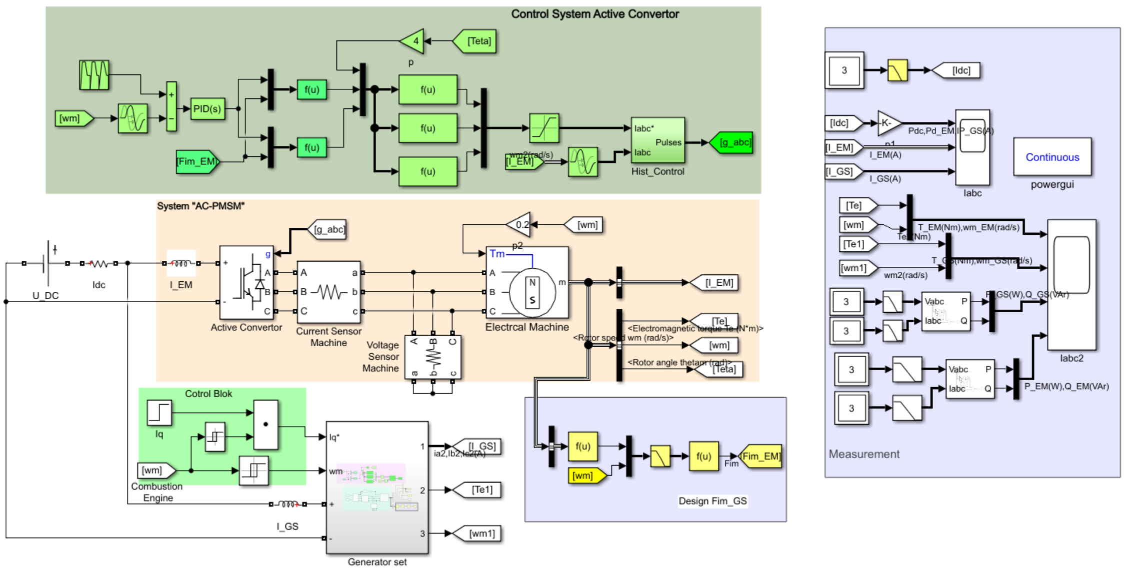


Figure 5 Virtual model in the SHMS system

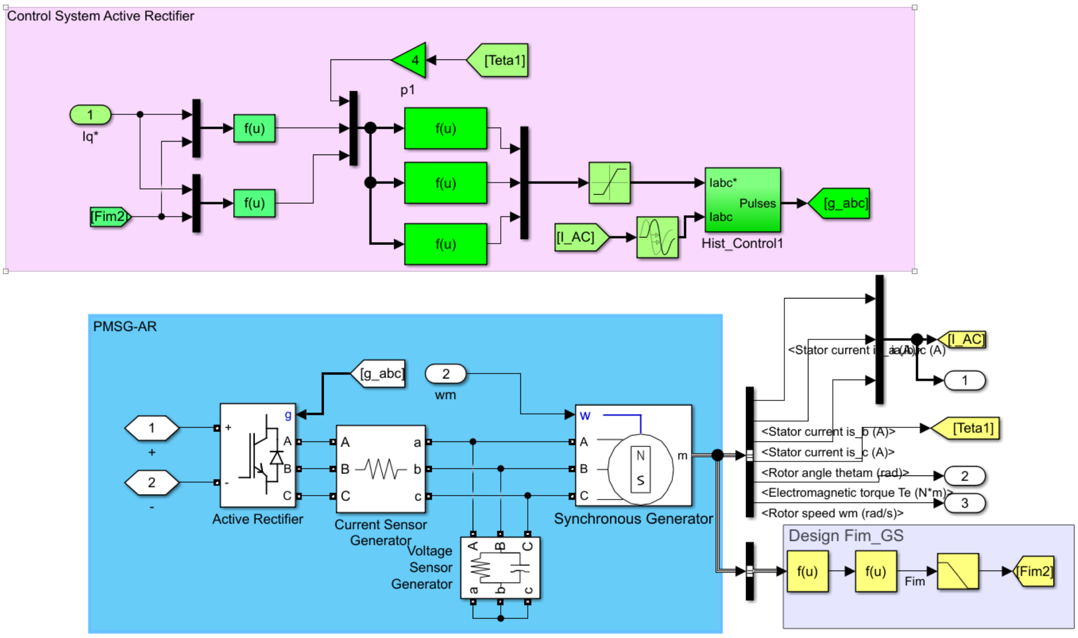


Figure 6 Virtual model of the generating set in the SHMS system

SHMS electromagnetic and energy processes (Figures 7-10) are presented with the use of the following oscillograms:

- Torque and rotational speed of the drive motor ($T_{EM}(Nm), \omega_{m\_EM}(rad/s)$);
- Torque and rotational speed of the generator ($T_{GS}(Nm), \omega_{m\_GS}(rad/s)$);
- Active and reactive power of the converter ($P_{EM}(W), Q_{EM}(VAr)$);
- Active and reactive power of the generating set ($P_{GS}(W), Q_{GS}(VAr)$);
- Battery power supply ($P_{dc}(W)$);
- power supply in the drive's DC circuit ($P_{d\_EM}(W)$);
- power supply in the generator's DC circuit ($P_{d\_GS}(W)$);
- Phase currents of the electric motor ($I_{EM}(A)$);
- Phase currents of the generator $I_{GS}(A)$.

The torque on the drive motor's shaft is set proportionally to the rotational speed (proportionally to the object's speed).

The independent variable in oscillograms is the relative time $t(pu) = \omega_b t, \omega_b = 314(rad/s)$.

Figure 7 and Fig.8 presents the complied oscillograms for FOC both in the drive and in the generator set.

In the first operating mode $t(pu) = 0 - 0.02\,pu$, the drive power is covered by the power (current) consumed only from the battery.

In the second and fourth operating modes, the generator supplies both the drive and the battery.

When decelerating ($t(pu) = 0.04 - 0.06\,pu$), in the third operating mode, the generator and the drive supply energy to the battery.

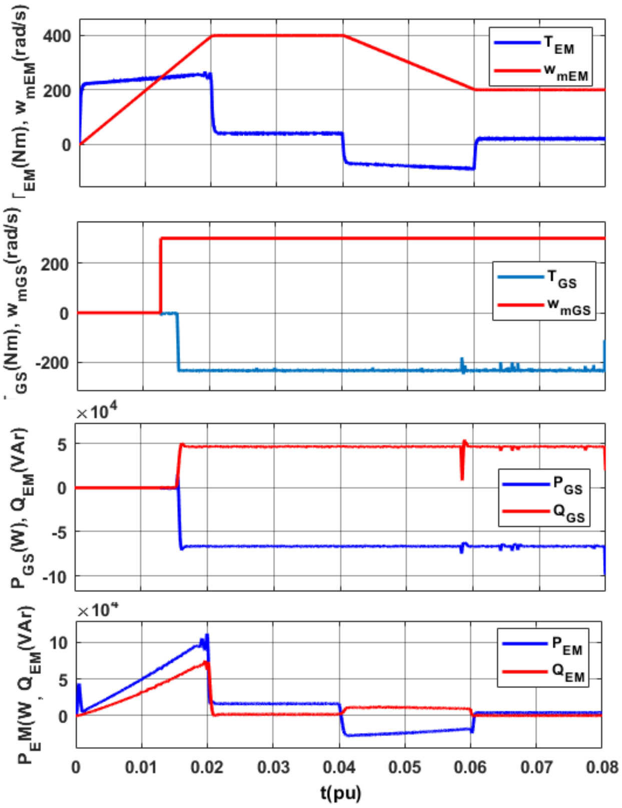


Figure 7 Energy processes in SHMS with FOC

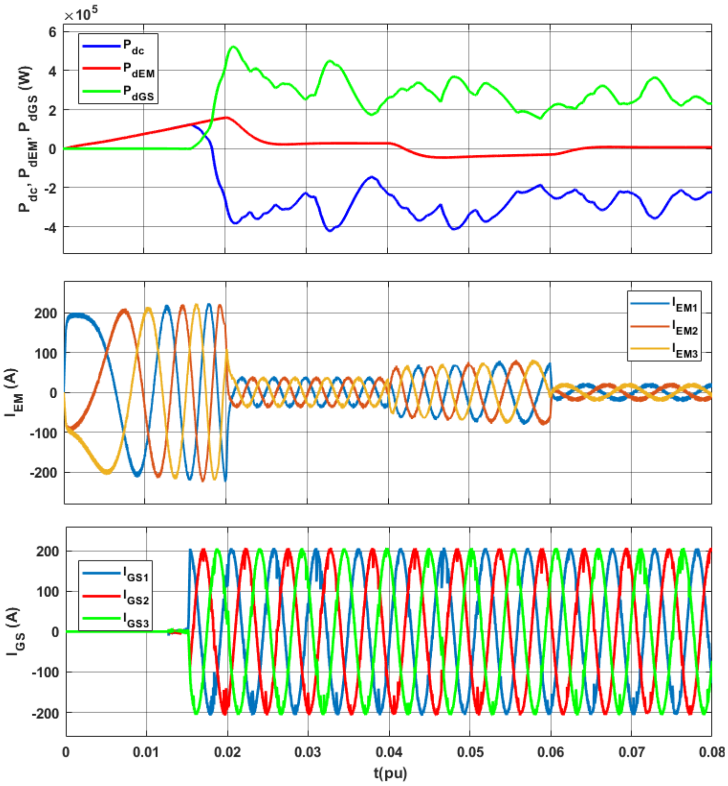


Figure 8 Electromagnetic processes in SHMS with FOC

Active and reactive powers in this control method are comparable in generator set. The electric drive at all speeds and torques operates in modes close to optimum due to the presence of speed feedback.

Figure 9 and 10 presents electromagnetic and energy processes taking place in SHMS with optimal control of both the generator set and the electric drive. By comparing Fig. 7 and Fig. 8, we can observe that the reactive power under optimal control (in both units) is equal to zero.

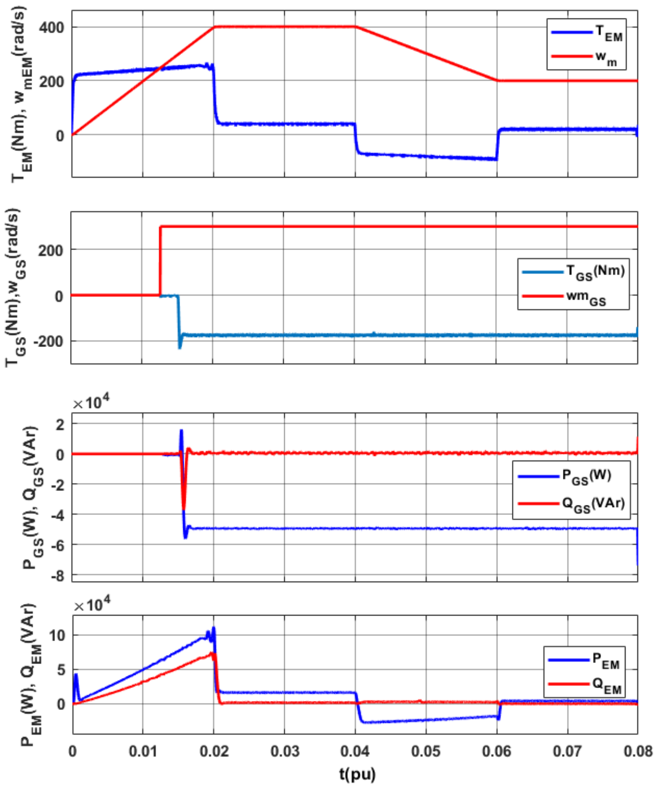


Figure 9 Energy processes in SHMS with optimal control

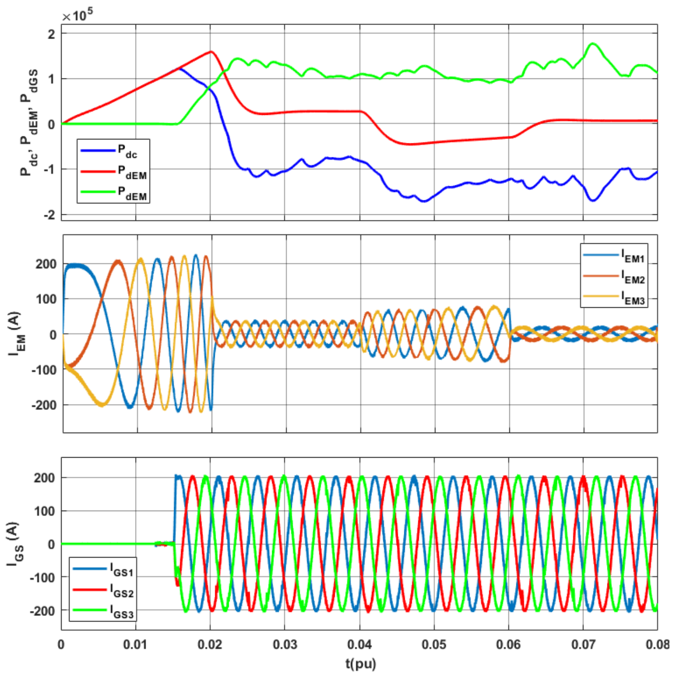


Figure 10 Electromagnetic processes in SHMS with optimal control

In a series hybrid mechatronic system with selected parameters of electric machines, a significant improvement of the energy performance is achieved by optimizing mainly the generator set.

5. CONCLUSION

Power semiconductor converters in intelligent systems and networks (Smart Grid) enable to build separate current sources (slave mode) and connect them in parallel with one voltage source (master mode), thus eliminating processes of exchangeable oscillation between these sources. In the analyzed series hybrid mechatronic system, the battery acts as a voltage source for the electric drive. The PMSM electric motor has a speed controller and the CE-PMSG generator set at the input. They act as regulated power sources with a power connection for one-way (for the generator) and two-way (for electric motor) power connection.

The virtual model prepared and presented in the article enables to study all possible cases of power redistribution of all three sources – both in steady and transient states. For SHMS with selected parameters of electric machines, a significant improvement in energy performance is achieved by optimizing the generator set – both via the selection of the optimal rotational speed of the generator and the optimal control of the active converter. In the SHMS electric drive part, it is important to exclude non-linear oscillations. This is ensured by the selection of the current limit value in the control system. The reactive power in the machine-converter systems (AR-PMSG and AC-PMSM) has been (practically) limited to zero. Therefore, the loss current in transmission lines has been reduced.

REFERENCES

[1] German-Galkin S., Tarnapowicz D. Energy optimization of mechatronic systems with PMSG. 3rd International Conference on Energy and Environmental Protection. Krakow, Poland, 2018, September 13-14, 2018, p.p 1-8. doi.org/10.1051/e3sconf/20184600016.

[2] Takahashi, Y., Matsumoto, R., Sasai, H. : Mechanical optimization of series hybrid electric vehicle with plant oil electric generator. 15th International Conference on Control, Automation and Systems (ICCAS), 2015, 13-16 Oct. 2015. DOI: 10.1109/ICCAS.2015.7364888.

[3] Jeong, Y (2009) .: Modeling and simulation of electric drive system for series hybrid electric vehicle. INTELEC, 31st International Telecommunications Energy Conference, 2009 18-22 Oct.DOI: 10.1109/INTLEC.2009.5351781

[4] Evangelou, S., Shukla, A. Advances in the modelling and control of series hybrid electric vehicles. 2012 American Control Conference (ACC) 2012, DOI: 10.1109/ACC.2012.6315156

[5] Mestriner, D. Feasibility Study of Supercapacitors as Stand-Alone Storage Systems for Series Hybrid Electric Vehicles. 2019 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE), 28-30 March 2019, Bucharest, Romania, DOI: 10.1109/ATEE.2019.8724997

[6] Tarnapowicz, D. Permanent magnet synchronous generators in a ship's shaft generator systems. SCIENTIFIC Journals of the Maritime University of Szczecin, 2020, Volume: 61 Issue: 133 Pages: 17-22 DOI: 10.17402/39.

[7] German-Galkin, S., Tarnapowicz, D., Energy Optimization of the 'Shore to Ship' System-A Universal Power System for Ships at Berth in a Port. SENSORS 2020, Volume: 20 Issue: 14 DOI: 10.3390/s20143815

[8] Bulgakov A.A. New theory of controlled rectifiers. - Nauka, Moscow, Russian.1970

[9] Kovacs, K.P.; Racz, I.(1959). Transient Processes in Alternating Current Machines; Transiente Vorgänge in Wechselstrommaschinen; Verlag der Ungar.: Budapest, Hungary, 1959.

[10] Ovchinnikov I.E. Brushless electric motors and drive on their basis (low and medium power) / I.E. Ovchinnikov: Course of lectures. KORONA - Vek, 2006 p- 336 p. St-Petersburg, Russia

[11] Brodovsky V.N., Ivanov E.S. (1974). Drives with frequency-current control. Energy, Moscow, Russian 1974.

[12] Slezhanovsky O. W. (1083). Systems of Slave Regulation of AC Electric Drive with Valve Converters. Energoatomizdat, Russia, 1983

SIMULATION ANALYSIS OF THE STABILIZATION OF THE HOOKS' BLOCK WITH THE USAGE OF A WIND DEFLECTOR

Andrzej Grządziela
Polish Naval Academy, Faculty of Mechanical & Electrical Engineering
Gdynia, Poland
E-mail: a.grzadziela@amw.gdynia.pl

Radosław Kiciński
Polish Naval Academy, Faculty of Mechanical & Electrical Engineering
Gdynia, Poland
E-mail: r.kicinski@amw.gdynia.pl

Bogdan Szturomski
Polish Naval Academy, Faculty of Mechanical & Electrical Engineering
Gdynia, Poland
E-mail: b.szturomski@amw.gdynia.pl

Paweł Piskur
Polish Naval Academy, Faculty of Mechanical & Electrical Engineering
Gdynia, Poland
E-mail: p.piskur@amw.gdynia.pl

UDK 621.873:627.21
519.876.5

Summary

Port cranes and gantry cranes used today have an increased load capacity. The increase in load capacity requirements applies to handling cranes in commercial ports and devices in production and repair yards. The conditions apply to shipyards executing orders in the field of offshore production and for wind energy. High-capacity cranes' design seems to be now a widely offered portfolio by key manufacturers around the world. The main problem for the giant gantry cranes is the wind considerable operational requirements. Safety regulations limit people's participation during loading or unloading to a wind speed above 9 m/s. In high-capacity gantry cranes, wind speeds even lower than 9 m/s can cause problems or even threats to the dynamic positioning of the hook's block above the load. Wind speeds above 9 m/s occur in the South Baltic bank from 110 to 140 days a year, indicating real operational problems. The paper presents a numerical analysis of the hook block movement trajectory subjected to variable wind effects. A simulation compared to test results of the same block equipped with a wind deflector reduces aerodynamic drag. The simulation results were calculated for the gantry, where the main girder is located at the height of 30 m. The test results show that using a deflector on a block significantly reduces the radius of the trajectory of movement and the hooks speed. The obtained results indicate that the reduction of the velocity and radius of the block's motion facilitates attaching the hook to the load and reduces the injury risks to operators.

Keywords: gantry crane, hooks' block, trajectory, simulations

1. INTRODUCTION

The shipbuilding industry often uses modular technologies, ensuring a fast production pace, high quality and just-in-time delivery of systems. Shipping system modules are elements whose weight ranges from several dozen kilograms up to 500 and more tons. The assembly of such large-size components for maritime or offshore vessels is a significant logistic challenge. The gantry crane can handle very broadly irregularly shaped pieces of construction produced and transported in shipyards. Safety regulations indicate that the human personnel involved in loading or unloading with the gantry crane limits their activity to the average wind speed over the gantry crane's entire height to 12 m/s. The dynamic impacts related to the irregularity of the wind gust and a change in its direction, first of all, make it impossible to precisely leave the lifting mechanism with a hook and ropes [4,5]. Another significant problem is lifting the module, which has an area much bigger than the hook block and the crane ropes.

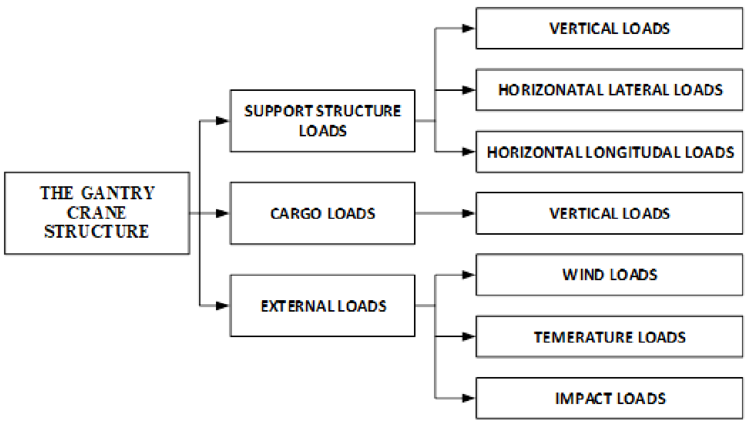
The object of research is the gantry crane with a capacity of up to 50 tons. The paper presents a simulation of the trajectory of classical hook block and the crane ropes in the conditions of wind speeds of 12 and 20 m/s. The work proposes using a hook block wind deflector, which reduces the air resistance coefficient and reduces the maximum diameter of the hook movement trajectory at the maximum overhang.

2. OBJECT OF RESEARCHES

The object of research is the gantry crane, which is in the conceptual design phase. The primary technical parameters are presented below:

- height of the crane leg - 30 m,
- width of the crane bridge - 38 m,
- weight of the maximum load - 50 t,
- number of wire ropes – 6,
- number of legs - 4.

Lifting cargo with a weight of up to 50 tons requires a substantial construction of all elements, starting from the frame structure, crane bridge, crab and ending with the wire rope, hook block and finally, the hook. The basic assumption is the correct analysis of the existing static and dynamic loads [10]. The results of the preliminary study are presented in Graph 1.



Graph 1 Structure of loads acting on the gantry crane

Source: Collins J. et al., 1991.

It was assumed that a block under the influence of wind behaves like a physical pendulum. The mass of the four slings and their stiffness were taken, where is k = 1250 N/m. The hook's block surfaces were determined from the CAD documentation, as were the cylindrical and spherical fairing surfaces. The simulations neglect the effect of the torsional moment of the stretched rope. This assumption is justified by the wire rope slings construction presented in Figure 1.

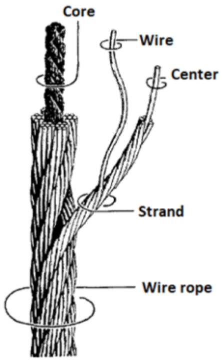


Figure 1 Construction of the wire rope slings

Source: Hoisting and Rigging Fundamentals for Riggers and Operators, 2002

The core is the center of the wire rope and serves as the foundation to hold the rope together. There are three types of cores, i.e. fibre, strand or Independent Wire Rope (IWR). The basic unit of the wire rope is the wire, mainly made from carbon steel. Finally, the strand, called cross lay strand, comprises a specific number of wires laid helically around a wire core. Spiral ropes can be dimensioned so that they are non-rotating, so under tension, the rope torque is almost zero.

3. AIR RESISTANCE OF HOOKS' BLOCK AND WIND DEFLECTORS

The aerodynamic force is the resultant of elemental forces exerted on the surface of a solid by the flowing fluid. The throw of force to the direction of velocity is called aerodynamic drag. In balanced flow, the aerodynamic drag consists of:

-pressure resistance, also called shape resistance (projection of normal in the direction $\vec{V}_\infty$

$$P_{xc} = \iint_s p\vec{n}\cos(-\vec{n}, \vec{V}_\infty)ds \#(1)$$

where $\vec{n}$- normal external of the arc element ds (see Fig. 3),

- frictional resistance (projection of the tangents in the direction of $\vec{V}_\infty$)

$$P_{xt} = \iint_s \vec{\tau}\cos(\vec{s}, \vec{V}_\infty)ds \#(2)$$

where by $(\vec{s}, \vec{V}_\infty)$ is understood the angle between the tangent to the profile having this same turn as $\vec{\tau}$, and the direction of velocity $\vec{V}_\infty$.

Their sum is the profile resistance, often called drag force:

$$P_x = P_{xc} + P_{xt} \#(3)$$

The mutual share of pressure and frictional resistance in the profile resistance depends on the shape of the body, its orientation concerning the flow direction, and the flow's nature in the boundary layer. For example, for a flat plate perpendicular to the direction of velocity, the pressure resistance is the entirety of the aerodynamic drag. For the same plate placed in parallel, the pressure resistance is zero, and the profile resistance is equal to the frictional resistance. For other shapes, e.g. cylinder or ball $P_{xc} \ll P_{xt}$for a low angle of attack aircraft profile $P_{xc} \gg P_{xt}$. Sometimes the total resistance maybe even slightly lower than the pressure resistance, as part of the contour is draped in the opposite direction to the resultant force P_x. Generally, it is assumed that "streamlined" shapes are those for which frictional resistance is the central part of the aerodynamic drag, and "non-streamlined" bodies are those for which frictional resistance is negligible compared to pressure resistance. Aerodynamic forces, and hence drag, can be measured by the following methods:

1) using the principle of conservation of momentum,
2) using the measurement of pressure distribution and tangential stress on the surface of the flowing body,
3) by weight (direct force measurement).

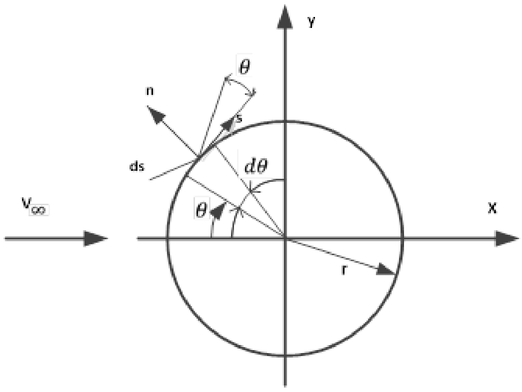


Figure 2 Coordinate system

It is accepted in the paper that "streamlined" shapes are those for which frictional resistance is the major part of the aerodynamic drag, and "non-flowing" bodies are those for which frictional resistance is negligible compared to pressure resistance. For the purposes of simulation, the principle of conservation of momentum was adopted in work. The determination of the influence of the relative roughness coefficient on the frictional resistance is shown in Figure 3.

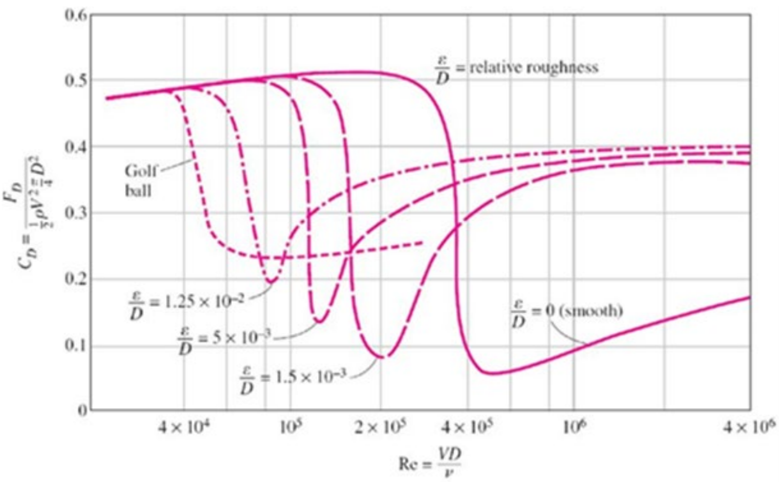


Figure 3 Roll resistance coefficient as a function of surface roughness and Reynolds numbers

Source: Matthew P., 2015

4. KINEMATICS ANALYSIS OF THE HOOKS' BLOCK

The Cartesian system uniquely assigns the coordinates of each point in space. In the description of the dynamics of the rotation of the physical pendulum for the vertical position, the sine of the angle takes the value zero. For a mathematical description of a pendulum, where the sine of the angle is in the denominator of the equation, it leads to ambiguity of the solutions. Therefore, a spherical coordinate system with a selected frame of reference was used in further analysis – see Fig. 4.

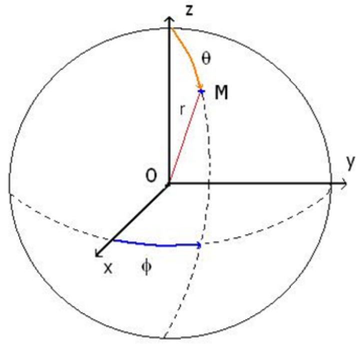


Figure 4 Spherical coordinate system

To any point, M it is assigned its spherical coordinates:

- leading radius r ⩾ 0, i.e. the distance of point M from the origin of the system O,
- length 0 ⩽ ϕ <2 π, i.e. the measure of the angle between the rectangular projection of the vector OM onto the Oxy plane and the positive half-axis Ox.
- the distance 0 ⩽ θ ⩽ π, i.e. the measure of the angle between the vector OM and the positive semi-axis Oz,

The relationship between the Cartesian coordinate system and the spherical coordinate system can be written using equation (1).

$$x = x(r,\theta,\phi) = r\sin\theta\cos\phi$$
$$y = y(r,\theta,\phi) = r\sin\theta\sin\phi \#(4)$$
$$z = z(r,\theta,\phi) = r\cos\theta$$

Similarly, for the adopted Cartesian coordinate system, the block coordinates (x_c, y_c, z_c) can be written, based on Figure 4, using the equation (5):

$$\begin{cases} x_c = Rcos(\alpha) \\ y_c = Rsin(\alpha)\, sin(\beta) \quad \#(5) \\ z_c = -Rsin(\alpha)\, cos(\beta) \end{cases}$$

The minus in the third equation (5) results from the adopted orientation of the z-axis. One should pay attention to the change of the coordinate system. The difference is caused by the need to avoid singular solutions that occur for small inclination angles of the crane block in inverse kinematics. This means that if the coordinate system was adopted as in Figure 5, where the projection of the R-length line is realized on the 0xy plane, for small block deflection angles, the sine value would be close to zero, which in some equations would result in dividing by zero.

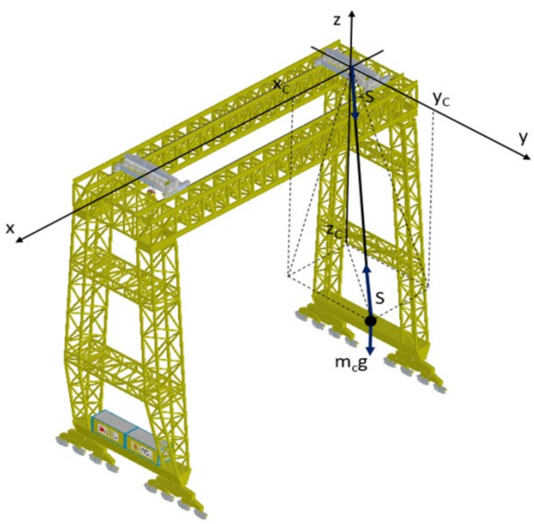


Figure 5 Cartesian coordinate system on the crane - isometric view

The change of the spherical coordinate system consists of projecting the line on the 0yz plane [9]. For the coordinate system adopted in this way, the block near the equilibrium point will occur for the angle α approximating 90 degrees, i.e. π/2 radians. Of course, the sine of the angle α for small angles will still be close to zero, but such a position will correspond to the forbidden states of the crane, i.e. those for which the pulley would be located in the horizontal plane.

Newton's second law of dynamics was used to present the dynamics of the gantry elements based on which the following equations:

$$F_x = a_x(m_w + m_c)$$
$$F_y = a_y(m_s + m_w + m_c) \ \#(6)$$
$$F_R = a_R m_c$$

The above equations present the description of the crane dynamics taking into account the mass of the block m_c, the mass of the crab m_w and the mass of the gantry frame m_s. The following forces' formulas were adopted:

F_x – the force acting on the drives along the x-axis;

F_y – the force acting on the drives along the y-axis;

F_R – the force acting on the drives along the ropes of length *R*.

The friction force should be included in the description of the crane dynamics. Friction is defined as the relationship directly proportional to the friction coefficient μ_T and the contact force F_N.

$$F_T = \mu_T F_N \#(7)$$

The pressure force is proportional to the weight of the crane components. The dynamics of the gantry depends on the friction force and the mass of the gantry crane elements according to the following relationship:

$$T_x = a_1(m_w + m_c)$$
$$T_y = a_2(m_c + m_w + m_s)\#(8)$$
$$T_R = a_3 m_c$$

where:

T_x – is the frictional (drag) force along the x-axis;

T_y – is the frictional (drag) force along the y-axis;

T_R – is the frictional (drag) force along the axis of the rope on which the hook block is suspended.

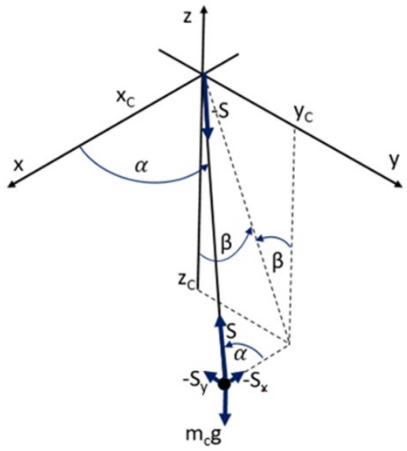


Figure 6 Forces acting on the block

The dynamics of the hook block (Fig. 6) can be written as follow:

$$S_x = m_c \ddot{x}_c$$
$$S_y = m_c \ddot{y}_c \quad \#(9)$$
$$S_z = m_c \ddot{z}_c + m_c g$$

The dynamics of the crab of the gantry (taking into account the dynamics of the block (m_C) and the mass of the gantry m_S, which is rigidly connected to the crab) can be written:

$$S_x - F_x = m_w \ddot{x_w} \#(10a)$$
$$S_y - F_y = (m_w + m_s)\ddot{y_w} \#(10b)$$

Equations (10) do not contain the equation of forces for the z-axis as the carriage does not travel vertically. The components of the force S_x, S_y, S_z of the rope's interaction with the trolley can be determined from the angular relations (Figure 6):

$$S_x = S\,cos(\alpha)$$
$$S_y = S\,sin(\alpha)\,sin(\beta)\ \#(11)$$
$$S_z = -S\,sin(\alpha)\,cos(\beta)$$

In equations (11), the components of the forces S_x, S_y, S_z are considered from the crab side. Therefore S_x, S_y have returns consistent with the *x*- and *y*-axes, while S_z is opposite to the *z*-axis. The equations assume that the rope is always tight. The force vector of the pulley acts on the crab, and it is directed from the crab towards the load.

$$S_x(x_c - x_w) + S_y(y_c - y_w) + S_z z_c > 0\#(12)$$

Assuming that the deviation of the rope from the vertical axis is slight, the trigonometric values of the angles can be written in a simplified form:

$$\cos(\alpha) = \cos\left(\frac{1}{2}\pi + \alpha\right) \cong -\alpha\#(13)$$
$$\sin(\alpha) = \sin\left(\frac{1}{2}\pi + \alpha\right) \cong 1\#(14)$$
$$\cos(\beta) \cong 1\#(15)$$
$$\sin(\beta) \cong \beta\#(16)$$

The system of equations (9) on the basis of simplifications (13) - (16) can be written:

$$S_x = -S\alpha$$
$$S_y = S\beta\ \#(17)$$
$$S_z = -S$$

Substituting the above dependencies (17) into the dynamics equations of the block (9), it obtains the following relations:

$S_x = -S\,\alpha$	$S_x = m_c\ddot{x}_c$	$\rightarrow$	$-S\,\alpha = m_c\ddot{x}_c$	(18)
$S_y = S\,\beta$	$S_y = m_c\ddot{y}_c$	$\rightarrow$	$S\,\beta = m_c\ddot{y}_c$	(19)
$S_z = -S$	$S_z - m_c g = m_c\ddot{z}_c$	$\rightarrow$	$-S - m_c g = m_c\ddot{z}_c;$	(20)

After transformations:

$$\ddot{x_c} = \frac{-S\,\alpha}{m_c}\#(21)$$
$$\ddot{y_c} = \frac{S\,\beta}{m_c}\#(22)$$
$$\ddot{z_c} = \frac{S}{m_c} - g\#(23)$$

Taking into account the system of equations (6) and the simplifications of the trigonometric values of the angles, it results:

$$\begin{cases} x_c = x_w - R\alpha \\ y_c = y_s + R\beta \\ z_c = -R \end{cases}\#(24)$$

By differentiating the above system of equations over time, we obtain dependencies on the hook block speed:

$$\begin{cases} \dot{x_c} = \dot{x_w} - \left(\dot{R}\alpha + R\dot{\alpha}\right) \\ \dot{y_c} = \dot{y_s} + \left(\dot{R}\beta + R\dot{\beta}\right) \\ \dot{z_c} = -\dot{R} \end{cases}\#(25)$$

By differentiating again over time, we get a system of the hook block acceleration equations:

$$\begin{cases} \ddot{x}_c = \ddot{x}_w - \left(\ddot{R}\alpha + \dot{R}\dot{\alpha} + \dot{R}\dot{\alpha} + R\ddot{\alpha}\right) \\ \ddot{y}_c = \ddot{y}_s + \left(\ddot{R}\beta + \dot{R}\dot{\beta} + \dot{R}\dot{\beta} + R\ddot{\beta}\right) \\ \ddot{z}_c = -\ddot{R} \end{cases} \#(26)$$

after adding the same components, equation (26) takes the final form:

$$\begin{cases} \ddot{x}_c = \ddot{x}_w - \left(\ddot{R}\alpha + 2\dot{R}\dot{\alpha} + R\ddot{\alpha}\right) \\ \ddot{y}_c = \ddot{y}_s + \left(\ddot{R}\beta + 2\dot{R}\dot{\beta} + R\ddot{\beta}\right) \\ \ddot{z}_c = -\ddot{R} \end{cases} \#(27)$$

By inserting dependencies from equation (27) into equations (21-23):

$$\begin{cases} \ddot{x}_c = \dfrac{-S\,\alpha}{m_c} \\ \ddot{y}_c = \dfrac{S\,\beta}{m_c} \\ \ddot{z}_c = \dfrac{S}{m_c} - g \end{cases}$$

and:

$$\begin{cases} \ddot{x}_w - \left(\ddot{R}\alpha + 2\dot{R}\dot{\alpha} + R\ddot{\alpha}\right) = \dfrac{-S\,\alpha}{m_c} \\ \ddot{y}_s + \left(\ddot{R}\beta + 2\dot{R}\dot{\beta} + R\ddot{\beta}\right) = \dfrac{S\,\beta}{m_c} \\ -\ddot{R} = \dfrac{S}{m_c} - g \end{cases} \#(28)$$

after removing the parentheses:

$$\begin{cases} \ddot{x}_w - \ddot{R}\alpha - 2\dot{R}\dot{\alpha} - R\ddot{\alpha} = \dfrac{-S\,\alpha}{m_c} \\ \ddot{y}_s + \ddot{R}\beta + 2\dot{R}\dot{\beta} + R\ddot{\beta} = \dfrac{S\,\beta}{m_c} \\ -\ddot{R} = \dfrac{S}{m_c} - g \end{cases} \#(29)$$

By isolating the unknown output variables $\ddot{\alpha}$, $\ddot{\beta}$, $\ddot{R}$, we obtained:

$$\begin{cases} \ddot{\alpha} = \dfrac{1}{R}\left(\dfrac{S\,\alpha}{m_c} - \ddot{x}_w + \ddot{R}\alpha + 2\dot{R}\dot{\alpha}\right) \\ \ddot{\beta} = \dfrac{1}{R}\left(\dfrac{S\,\beta}{m_c} - \ddot{y}_s - \ddot{R}\beta - 2\dot{R}\dot{\beta}\right) \\ \ddot{R} = g - \dfrac{S}{m_c} \end{cases} \#(30)$$

By adding to the above equations two equations describing the dynamics of the crab (10):

$$\begin{cases} S_x - F_x = m_w\,\ddot{x}_w \\ S_y - F_y = (m_w + m_S)\ddot{y}_w \end{cases}$$

and transforming with respect to unknown values $\ddot{x}_w$, $\ddot{y}_w$ it get:

$$\begin{cases} \ddot{x}_w = \dfrac{1}{m_w}(S_x - F_x) \\ \ddot{y}_w = \dfrac{1}{m_w + m_S}\left(S_y - F_y\right) \end{cases} \#(31)$$

Combining equations (30) and (31), it get five second-order nonlinear equations:

$$\begin{cases} \ddot{\alpha} = \frac{1}{R}\left(\frac{S\,\alpha}{m_c} - \ddot{x}_w + \ddot{R}\alpha + 2\dot{R}\dot{\alpha}\right) \\ \ddot{\beta} = \frac{1}{R}\left(\frac{S\,\beta}{m_c} - \ddot{y}_s - \ddot{R}\beta - 2\dot{R}\dot{\beta}\right) \\ \ddot{R} = g - \frac{S}{m_c} \\ \ddot{x_w} = \frac{1}{m_w}(S_x - F_x) \\ \ddot{y_w} = \frac{1}{m_w + m_S}\left(S_y - F_y\right) \end{cases} \#(32)$$

The input data are the forcing forces F_x, F_y and S, and the output data are the vertical position of the rope with the hook block and the horizontal position of the crab. The hook block and crane weights, as well as the acceleration due to gravity, are constant.

The study considered three hook blocks i.e. without wind deflector, with a spherical deflector and a cylindrical fairing (Fig. 7). Depending on the variant, the hook block under wind loads will move a different trajectory.

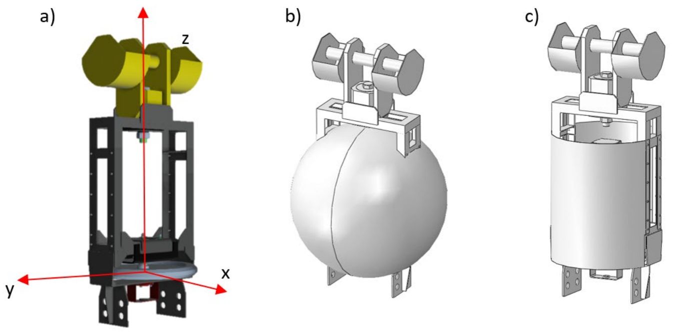


Figure 7 Hook block in various configurations a) without deflector, b) with a spherical deflector, c) with a cylinder-shaped fairing.

The first stage of calculations is to determine the air pressure force on the hook block. This force is equal to the air resistance acting on the block and takes the following form [1] :

$$R_A = C_A \rho_p \frac{v_p^2}{2} A_Z \#(33)$$

where:

- ρ_p is the air density in kg/m3,
- v_p is the wind speed in m/s,
- A_Z is the area of the block's transverse projection to the wind direction in m^2,
- C_A is the coefficient of air drag.

Based on the anemometer research, it was assumed that the wind amplitude changes according to the formula:

$$R_W = R_A + 0{,}15 R_A \sin(0{,}2 \cdot t) \#(34)$$

and that the wind in the horizontal plane xOy changes its direction according to the formula:

$$\begin{matrix} R_{WX} = R_W \sin(0{,}8t) \\ R_{WY} = R_W \cos(0{,}8t) \end{matrix} \#(35)$$

According to the formula (33), the surface area on which the wind acts depending on the direction should be determined. The coordinate system and the directions of wind action were determined, and then the loads were assumed following the formulas (34), (35). The area of the wind force was determined using

CAD (Computer-Aided Design) tools. In the case under consideration, for a block without fairings, the surface area for two directions of wind load should be determined; in the case of using symmetric fairings, the cross-sectional area does not change regardless of the direction the force.

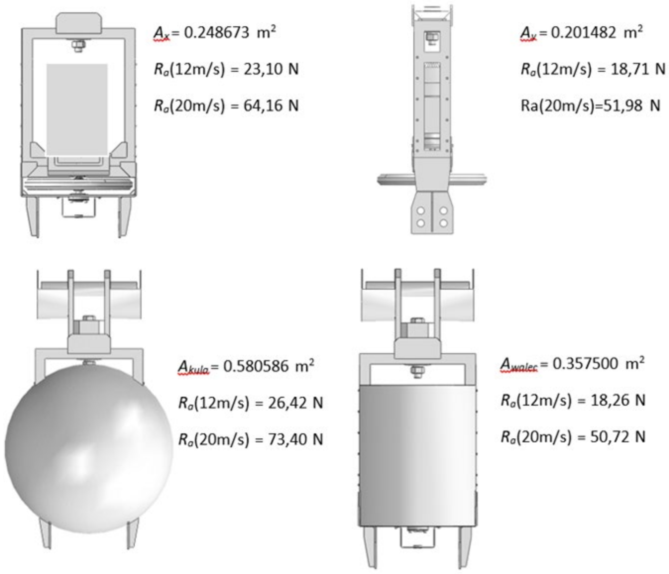


Figure 8 Surface areas and forces acting on hook blocks (the typical block, sphere fairing and cylinder deflector) depending on the wind force

After calculating the block area in various fairing configurations, based on the literature [2], the values of the air resistance coefficients were determined:

$C_{A\text{-}Z}$ – drag coefficient for the hook block = 1,
$C_{A\text{-}W}$ – drag coefficient for a cylinder deflector = 0,55,
$C_{A\text{-}K}$ - drag coefficient for a sphere firing = 0,49.

Then, the forces generated by the wind for two wind speeds (12 and 20 m/s) were determined, depending on its direction of operation (Fig. 9).

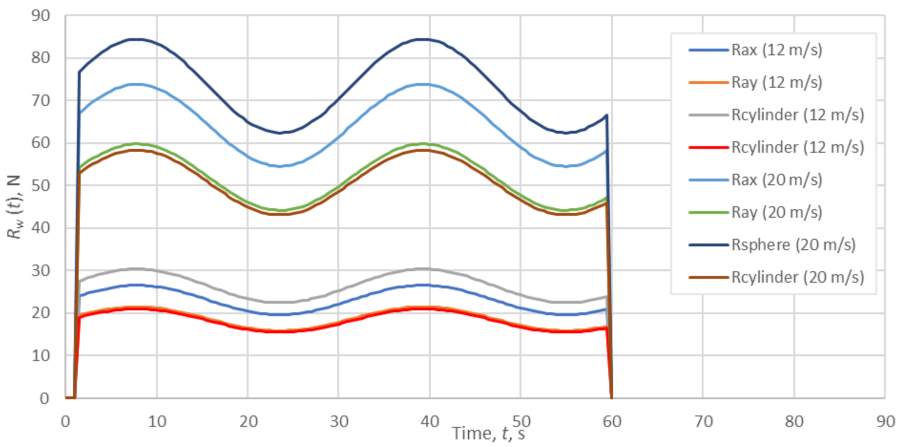


Figure 9 Change of the maximum values of the wind force depending on the hook block variant

This force changes its value in two directions (*x, y*) according to (33), so the block will move along a specific trajectory. The hook block can be considered as a physical pendulum (Fig. 10). Thus, the amplitudes and trajectories of motion can be determined using the appropriate mathematical description presented, and programs support engineering calculations to determine the block moments of inertia and equations of motion. In the case of uniform wind, the pendulum will move along a trajectory close to an ellipse. However, in the proposed model, both the value and the direction of force application change, which will affect the trajectory.

The wind loads the hook block. It will behave like a cycloidal pendulum, i.e. a pendulum. A thread or elastic suspension element will wrap around a cycloid with a horizontal axis and a radius equal to a quarter of the pendulum's length [3]. The problem of a pendulum with an amplitude-independent period comes down to determining such a curve that the body, moving along it under the action of the constant force of gravity, will move from the starting point to its lowest point at the same time. The curve is called a tautochrone and is a cycloid.

The problem of pendulum motion can be solved by approximating the sine function to two terms, then the equation of pendulum motion takes the form:

$$\frac{d^2\theta}{dt^2} + \frac{g}{l}\left(\theta - \frac{1}{6}\theta^3\right) = 0\#(36)$$

The solution to the above equation has approximately the form (with the accuracy of terms of the 3rd order):

$$\theta(t) = \theta_0 \cos(\omega t) + \theta_3 \cos(3\omega t)\,\#(37)$$

where:

θ_0- vibration amplitude with a frequency of *ω,*

$\theta_3 = \frac{1}{3}\left(\frac{\theta_0}{4}\right)^3$ - vibration amplitude with a frequency of 3*ω,*

$\omega_0 = \sqrt{\frac{g}{l}}$,

$\omega = \omega_0\left(1 - \frac{\theta_0^2}{16}\right)$.

Substituting the wind model for amplitude can obtain the cycloid equation described in the general case by the parametric equation:

$$\begin{matrix} x = rt - c \cdot \text{sint} \\ y = rt - c \cdot cost \end{matrix}\#(38)$$

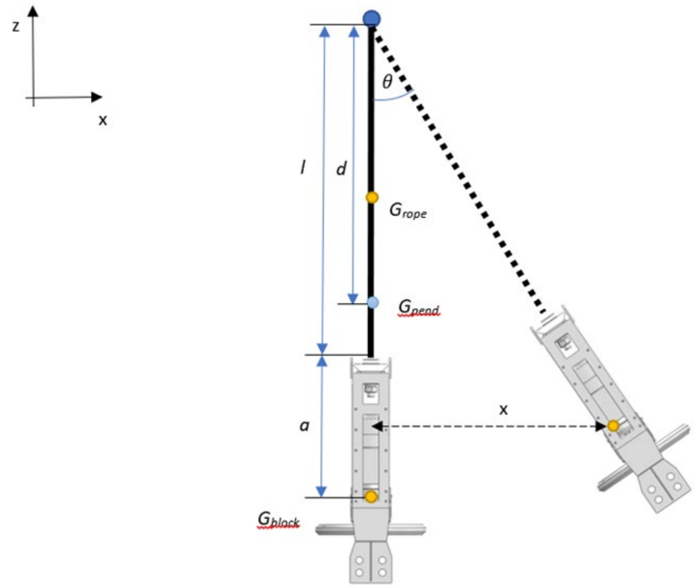


Figure 10 The hook block as a physical pendulum

The dependence of the distance c of the point marking the curve on the centre of the rolling circle and the radius r of this circle is as follows:

- for c <r a shortened cycloid, defined by a fixed point lying inside a rolling circle;
- for c> r an elongated cycloid defined by a fixed point lying outside the circle;
- for c = r a normal cycloid drawn by a point on the edge of the circle.

Depending on the strength of the wind at a given moment in time, c and r take different values. Thus, after substituting all dependencies, the approximate trajectory of the block for different wind speeds can be determined.

Determining the trajectory of the hook block is a challenge for analytical calculations, therefore in these considerations, it was decided to use FEM (finite element method) to determine the trajectories.

5. FEM ANALYSIS OF THE MOVEMENT OF THE HOOK BLOCK

As rope modelling is a complicated issue, some simplifications have been used in the presented approach. The first is the use of beam elements as perfectly rigid bodies to model the rope. This approach is justified when heavy loads are hanging on the ropes. The mass of the block is 102.5 kg, so it can be assumed that the above statement is correct. Moreover, the forces acting on the block were determined directly from the formulas, so it is not necessary to model the entire block. Hence the movement of the pendulum comes down to the analysis of a material point suspended on an inelastic thread. The centre of gravity of the physical pendulum, taking into account the rope weight, was determined to be 12 m.

The next step was to determine the block trajectory depending on the input value. The wind load was 60 s, and then for the following 180 s, the traffic of the hook block - the centre of gravity was analysed (240 s in total). The results are presented for two input speeds, 12 m/s and 20 m/s, for three variants of the block structure. The case-by-case trajectory of the hook blocks is shown below.

The analysis of the trajectory of the centre of gravity of the hook block indicates that the most effective solution is the use of cylindrical fairing. The symmetrical shape, low roughness and small surface area effectively reduce wind speeds on the hook block for both analysed wind speeds.

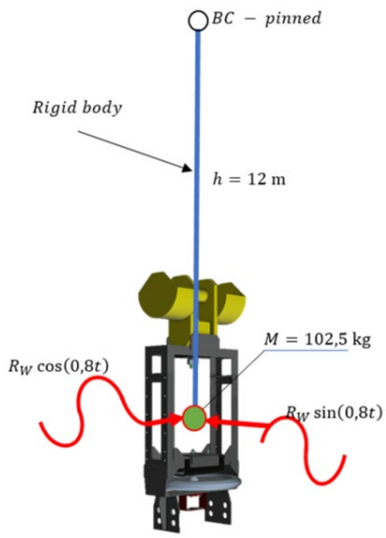


Figure 11 Boundary conditions and load diagram in the FEM simulation

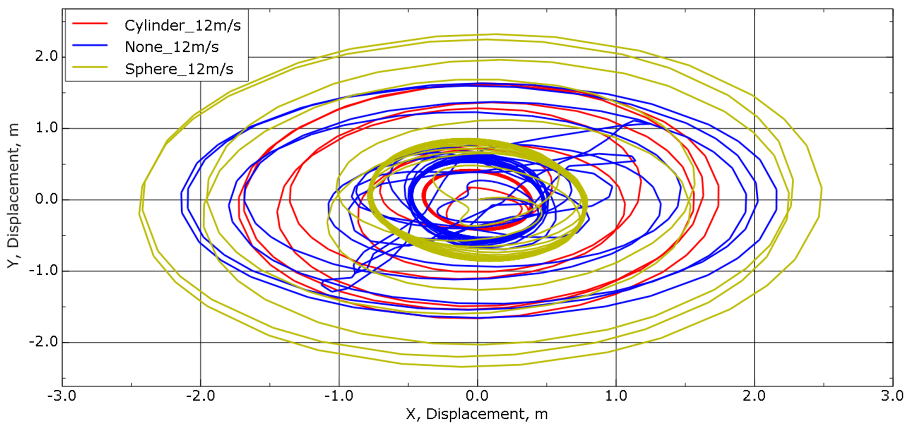


Figure 12 Movement trajectories of hook blocks in different variants for a wind speed of 12 m/s

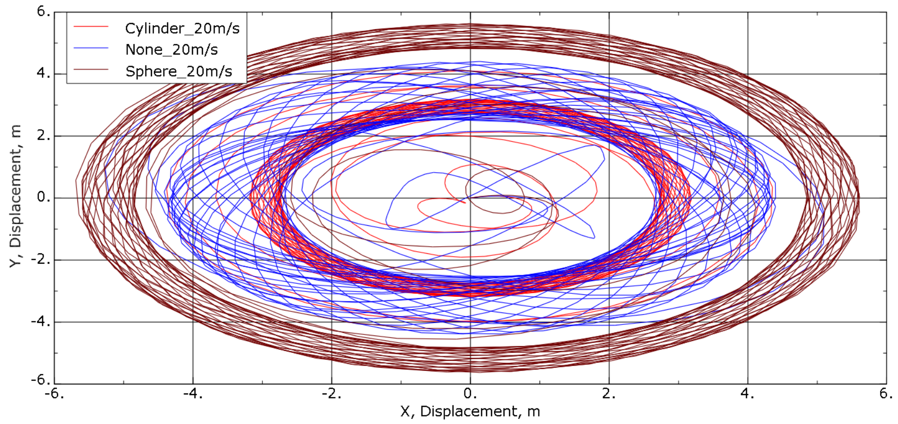


Figure 13 Movement trajectories of hook blocks in different variants for a wind speed of 20 m/s

6. CONCLUSION

Based on the analysis, it can be concluded that:

- The use of FEM allows to determine the block trajectory using commercial code;
- The fairings have a significant influence on the block trajectory. Due to the lowest drag coefficient, the ball appears to be the most suitable shape as a fairing. However, a fairing in this shape increases the surface area affected by the wind. According to the analysis, the spherical deflector increases the deflection angles. The advantage of using deflectors is the systematization of the trajectory.
- The cylinder-shaped deflector has a similar advantage to a sphere. It increases the cross-sectional area affected by the wind, but not as much as a sphere. Analyses of the trajectories show that the cylinder-shaped fairing has the most significant impact on reducing the block deflection angle.
- The simulations do not consider the frictional forces in the block bearings or the air resistance to prevent the block from moving after the force is stopped. The only force that prevents the block from moving is gravity. The analyse of the block movement in more detail, model block mounting and air resistance should be analysed after the force has ceased to be modelled. Such a task is more complicated and may be considered in later studies.
- The use of cylindrical fairings on the blocks of cranes operating in ports can significantly facilitate the work of loading and prevent accidents related to the inertia of the hook block when suspending the load.

REFERENCES

[1] Charchalis A.: Opory Okrętów Wojennych i Pędniki Okrętowe (Resistance Force of Warships and Ship Propellers - in Polish); Akademia Marynarki Wojennej im. Bohaterów Westerplatte: Gdynia, 2001;

[2] Baker, W.E., Cox, P.A., Kulesz, J.J., Strehlow, R.A., Westine, P.S.: Explosion Hazards and Evaluation; Elsevier Science: Saint Louis, 2014; ISBN 978-0-444-59988-9.

[3] Emmerson, A.W.: Things Are Seldom What They Seem: Christiaan Huygens, the Pendulum, and the Cycloid. NAWCC bulletin 2006.

[4] MacCrimmon R.A.: Crane-Supporting Steel StructuresDesign Guide, Canadian Institute of Steel Construction, Toronto, Canada, 2005.

[5] AS 1418.1-1994: Cranes, Part 1: General requirements. Standards. Australia, 1994.

[6] Collins J., MacKenzie R., Pospisek K., Kames W.: The design and long term performance of heavy duty brane beams. Trends on Steel Structures for Mining and Building. South African Institute of Steel Construction, Johanesburg, South Africa, 1991.

[7] Hoisting and Rigging Fundamentals for Riggers and Operators, TR244C, Rev. 5, December 2002

[8] ISO 8686-1:1989: International Standards: Cranes – Design principles for loads and load combination, Part 1: General. International Organization of Standardization, Geneva, Switzerland, Nov. 1989.

[9] Ricker D.T., Tips for avoiding crane runway problems, American Institute of Steel Construction Engineering Journal, 4th Q., 1982, pp.181-205.

[10] Rowswell J.C.: Crane runway systems. Master’s thesis, Civil Engineering, University of Toronto, Canada, 1987.

[11] Matthew P. Juniper. Fluid Mechanics, 2015.

ANALYSIS OF NEAR-MISS EVENTS ONBOARD SHIPS

Nermin Hasanspahić
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: nermin.hasanspahic@unidu.hr

Srđan Vujičić
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: srdjan.vujicic@unidu.hr

Vlado Frančić
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: vlado.francic@pfri.uniri.hr

Maro Car
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: maro.car@unidu.hr

UDK 656.61.085 :331.45

Summary

Despite increasingly stringent regulations and rules, the use of modern equipment on ships, and the implementation of additional training and education for seafarers, accidents in the shipping industry continue to happen. The consequences of accidents vary from minor injuries and material damage to severe casualties, complete loss of ships and cargo. It is in the interest of all stakeholders in the shipping industry to reduce risks and improve safety, but still, only after severe accidents corrective measures are taken, i.e. new ways to improve safety are sought. In contrast to such an approach, a proactive approach is proposed, which would try to prevent the occurrence of accidents. One way that could make this possible is a near-miss management system. Such a system must be as simple as possible and adapted to the shipping industry to be effective. The authors used a survey questionnaire to investigate the opinion of officers and masters about the near-miss management systems implemented on their ships. An analysis of the responses showed that they are relatively satisfied with the current near-miss management system on their ships but still believe that a large proportion of seafarers still do not report all near-misses due to specific barriers. Furthermore, officers and masters believe that most near-misses are related to operation on deck, followed by the engine room activities.

Keywords: near-miss management, accident, personal protective equipment, maritime safety

1. INTRODUCTION

Marine accidents of various proportions are continuously occurring despite increasingly advanced modern technologies introduced on merchant ships and the education and training of seafarers. The question is how to reduce their number and reduce risks. First of all, a marine accident needs to be defined. It is an unexpected unintentional sequence of events that caused harmful outcomes that put human lives, property, and the marine environment in direct danger [1-3]. Reducing the number of marine accidents and increasing safety at sea is one of the goals of all stakeholders in the shipping industry. There are several ways to achieve it: investigating accidents and implementing safety measures originated from accident investigations results and safety recommendations or investigating near-miss events and implementing lessons learned into onboard policies and procedures [3,4]. The first one presents a corrective approach to safety improvements, while the second is a proactive approach. A proactive approach means that safety improvements are implemented before any damage, injury, fatality or environmental pollution was done, based on analysis of an event that is the precursor of an accident – a near-miss [3-5]. It is an unwanted event that could have caused adverse consequences for human lives, property, and the marine environment, but it did not. The harmful outcome was avoided by a fortuitous break in the chain of events [3,4,6]. It is an excellent possibility and opportunity to reduce unwanted events since there is no harm done and no additional costs, like after some catastrophic accidents [4].

A near-miss management system needs to be introduced onboard a ship to investigate near-misses and find their immediate and root causes, identifying corrective measures that need to be implemented. The system must be as effective, as simple as possible and applicable to be an adequate tool for safety improvements. According to the available literature review, the near-miss management system is comprised of eight elements or phases:

1. Identification is a first phase where the seafarer identifies possible near-miss events [3, 7-12];
2. Reporting is a phase where the seafarer decides to report observed near-miss event (either to his superior officer or he reports it by himself) [3,7-14];
3. Prioritisation includes rating the importance of hazard that near-miss event could have caused and assessment of the proportion of the causation analysis [3,7-10,12-14];
4. Distribution of near-miss data to the person in charge of corrective actions [3,8-11,14];
5. Cause analysis where immediate and root causes are identified [3,7-13];
6. Solution identification includes corrective actions aiming to prevent recurrence or mitigate possible near-miss consequences [3,7-12,14];
7. Dissemination of near-miss data and implemented corrective measures [3,7-11,13,14];
8. Resolution is a final phase where corrective actions are implemented and evaluated [3,8-14].

The first two phases are crucial for a practical and usable near-miss management system. If seafarers cannot identify near-miss events or are unwilling to report them, such a system could be considered inadequate. The seafarer needs to be trained and familiar with the definition of the near-miss to identify it [3,4].

Even though near-miss reporting and analysis might lead to valuable conclusions and implementation of corrective measures, studies showed that seafarers are not reporting all observed near-misses. There are several barriers to reporting identified in literature dealing with near-miss reporting. Besides near-miss identification, the literature review revealed several significant reporting barriers, like blame culture, inadequate leadership, the complexity of near-miss reporting form, seafarer's national culture and crewmember's turnaround on a specific ship [1,3,4].

2. METHODOLOGY

This paper aims to gain insight into seafarers' opinions on the near-miss management systems implemented on their ships and reveal the most hazardous areas onboard ships. Furthermore, the paper tries to identify the most common types of near-misses and propose proactive measures. The research tool was a survey developed by the authors. The first part of the survey were seven demographics questions, followed by 12 questions on the near-miss management system in the second part. Demographics questions dealt with respondents nationality, age, rank, education, ship type, service time in rank and sea service time. Questions on near-miss management systems were predominantly closed type questions. There were four simple yes/no/I don't know questions (Q1-Q3, Q11), four five-point Likert scale questions (Q5-Q8), two checklist type multiple-choice questions (Q4 and Q12) and one rank order multiple choice question (Q10). One question was open-ended where respondents had to type their answers (Q9).

The survey questions were neutral to avoid biased participation. The prepared survey was available online, and a web link was sent to several crew recruitment agencies. They shared it with seafarers, who shared it with their colleagues (virtual snowball sampling). Each seafarer could freely choose whether to participate in the survey or not, and the participation was confidential and anonymous. A total of 112 seafarers participated in the survey.

3. RESULTS AND DISCUSSION

Eight nationalities were represented in the survey, 90% of participating seafarers being from Croatia (Figure 1).

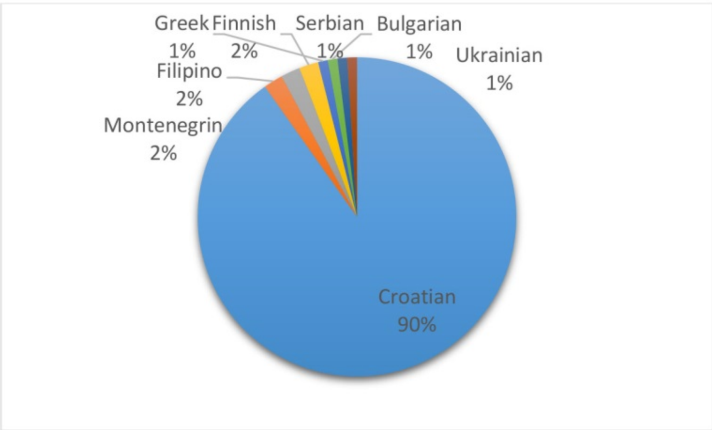


Figure 1 Nationalities of participating seafarers

The age of the respondents is presented in Figure 2. Most of the respondents were aged 42 and under (70%).

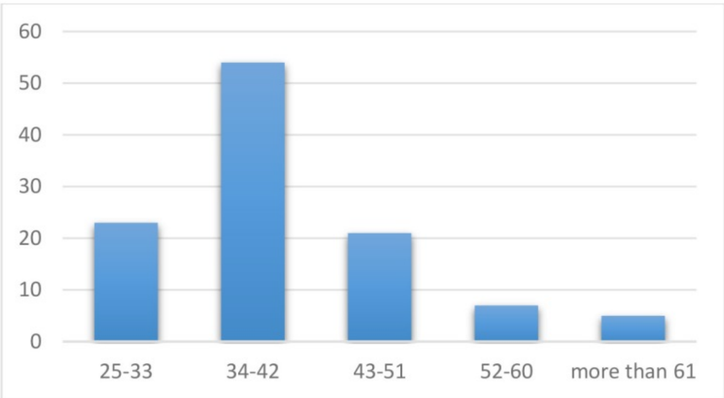


Figure 2 Age distribution of the participating seafarers

Just over half of the respondents (51%) were ranked as Masters and Chief Officers (Figure 3).

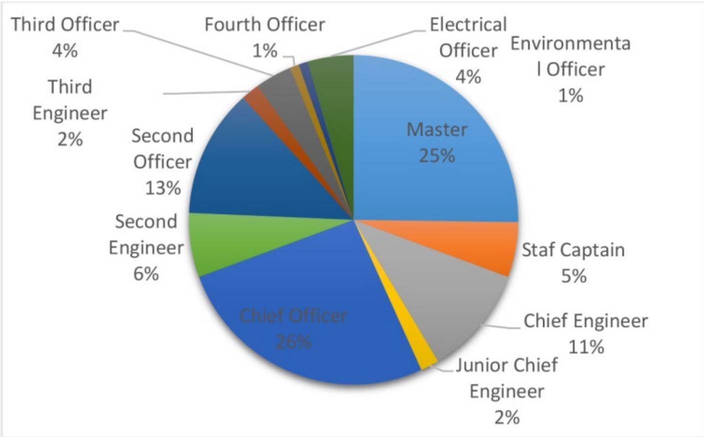


Figure 3 Reported ranks of participating seafarers

Most of the participants reported being educated at a maritime college (Figure 4).

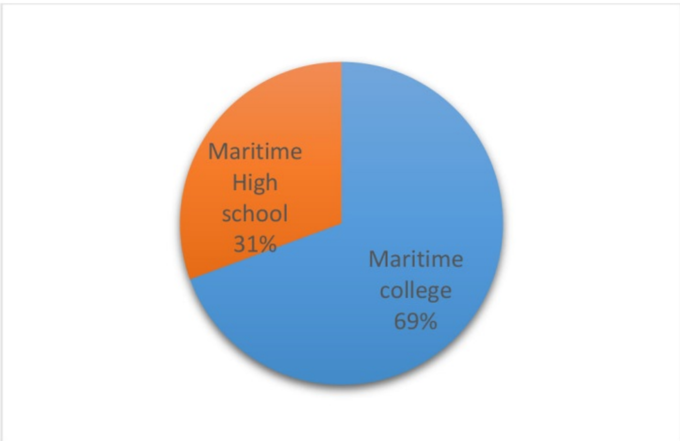


Figure 4 Type of education of participating seafarers

Participating seafarers sailed on different ship types, where oil tankers, LNG tankers and cruise ships were the most represented ship types (77%). Figure 5 presents participants' ship types.

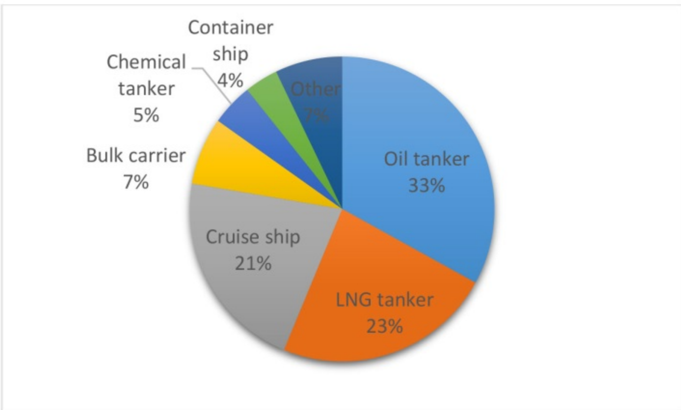


Figure 5 Ship types of participating seafarers

Other ship types included Ro-Ro passenger ships, tug boats, AHTS (Anchor Handling Tug Supply ship), PSV (Platform Supply Vessel), FLNG (Floating Liquified Natural Gas) and FSRU (Floating Storage Regasification Unit) ship.

Most of the surveyed seafarers reported serving in the present rank for six years and less (Figure 6).

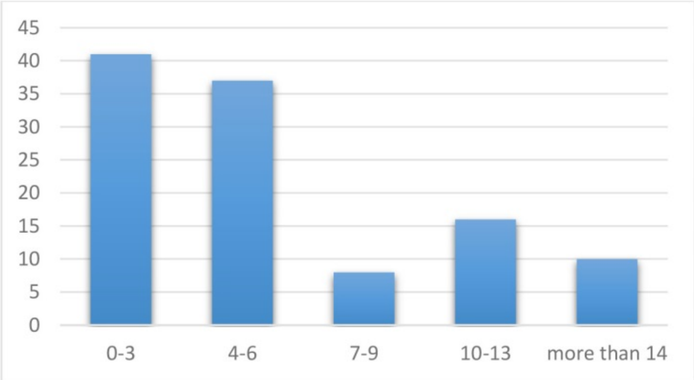


Figure 6 Surveyed seafarers reported service time in the rank

Most participants reported between 6 and 17 years of sea service (61%). Figure 7 presents respondents sea service time.

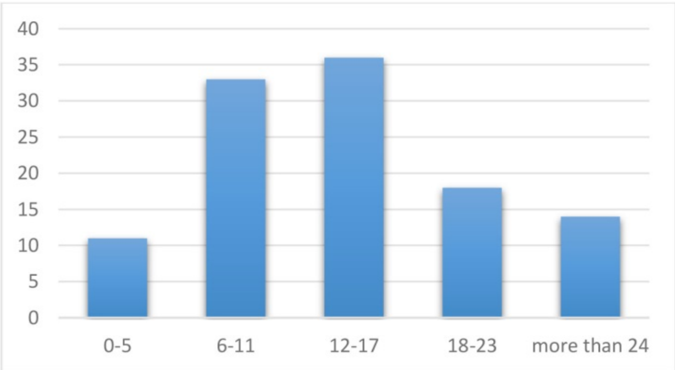


Figure 7 Surveyed seafarers reported sea service time

Analysis of demographics questions showed that surveyed seafarers are well experienced and educated professionals. In the following section, the results of the survey are presented and discussed.

IMO Model Course 3.11 "Safety investigation into marine casualties and marine incidents (2014 Ed.)" deals with reporting and investigation of accidents, incidents and near-misses. Also, several tailor-made courses are developed by training centres or shipping companies, based on IMO Model Course 3.11. These courses incorporate topics of accident, incident and near-miss reporting and investigation. However, they are not mandatory, and some companies are unwilling to invest money in non-mandatory courses.

The first near-miss management question in the survey was: have you received formal training for accident/incident/near-miss investigations (Q1). More than half of the participants answered affirmatively (Figure 8). Formal training is considered training provided in a shore-based training centre and not onboard training. That kind of training is implemented to improve safety awareness onboard ships, facilitate accidents/incidents investigations, and enable safety culture maturing.

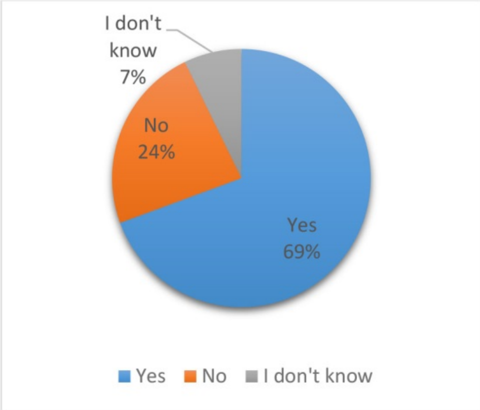


Figure 8 Answers to the question "Have you received formal training for accident/incident/near-miss investigations?"

It means that most of the respondents (primarily senior officers onboard ships) are trained to investigate incidents, find immediate and root causes and propose corrective actions. However, it is not the case with all respondents, and there is still many masters and safety officers who have not received adequate training for incident investigation.

Answers to the following question revealed that most surveyed seafarers believe that such training should be mandatory (Q2) (Figure 9).

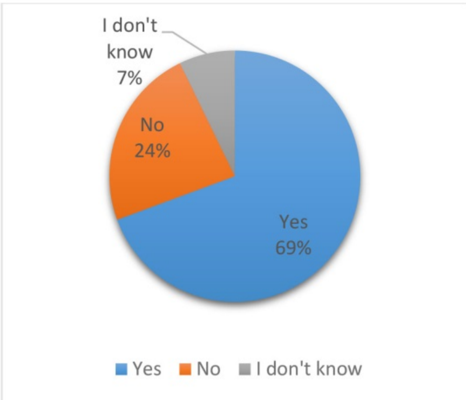


Figure 9 Answers to the question "Do you think that formal training regarding accident/incident/near-miss investigations should be mandatory?"

The introduction of mandatory incident investigation training would enable more efficient and thorough hazardous events investigations, and in return, it could identify unknown root causes and implement corrective measures that could improve safety at sea. Furthermore, safety culture in shipping could benefit from such training because seafarers are familiarised with no blame culture, safety culture and advantages of incident reporting.

Figure 10 presents the ranks of seafarers answering affirmatively to Q2. Analysis of the answers showed that more seafarers that belong to the deck department think that accident/incident/near-miss investigations training should be mandatory (75% of affirmative answers to Q2) than the seafarers that belong to the engine room department (25% of affirmative answers to Q2). Furthermore, analysis of affirmative answers revealed that 36% of respondents work on oil tankers, 25% on LNG carriers, 25% on cruise ships, 6% on bulk carriers and the remaining 8% on other types of ships (chemical tankers, container ships, FLNG and FSRU).

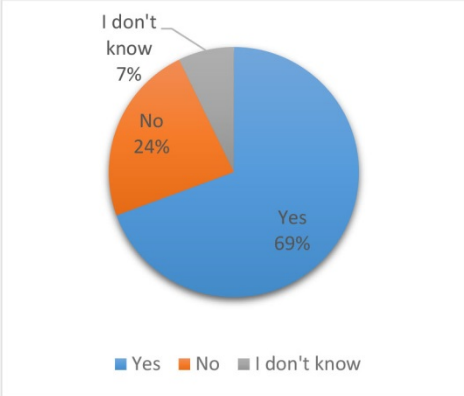


Figure 10 Ranks of seafarers thinking that accident/incident/near-miss investigation training should be mandatory

The participants were asked do they encourage their fellow crewmembers to report all observed near-misses (Q3). The vast majority of seafarers actively encourage their colleagues to report near-misses, but some officers are still reluctant to report hazardous events and reported that they do not encourage their crewmembers (Figure 11).

Figure 11 Answers to the question "Do you encourage your crewmembers to report all near-misses?"

Although a relatively small number of seafarers do not encourage reporting, the troubling fact is that they are all holding officers ranks, and they manage with people and assets onboard ships.

When asked which onboard location is the area where most of the near-misses occur (Q4), surveyed seafarers reported deck area (43%) and engine room (35%) as the most hazardous areas onboard a ship (Figure 12).

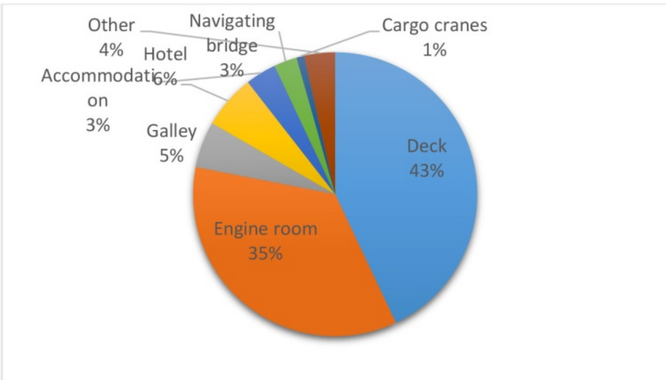


Figure 12 Answers to the question: "Which onboard location, as per your own experience, is a location where most near-misses occur?"

Answers to Q4 are in line with the American Bureau of Shipping (ABS) research [15]. They analysed the 45298 near-miss reports they collected in their database regarding near-miss causation, ship type, near-miss location onboard a ship and category (type) of near-miss event. Their analysis revealed that 37% of all near-misses collected in their database occurred on the deck. It can be concluded that the deck area is the most dangerous ship's area, and extra care should be taken accordingly.

Table 1 contains the following four questions given on the five-point Likert scale.

Table 1 Likert scale questions

No	Question	Mean	Standard deviation
Q5	Do you think that crewmembers onboard your vessel report all near-misses they observe?	2.52	1.09
Q6	Do you think that near-miss follow up measures received from the company are substantial and applicable to your vessel?	3.52	1.09
Q7	Do you agree that near-misses should be rated (given low or high priority) before sending them to the office (to the designated person ashore)?	3.40	1.18
Q8	Please rate satisfaction with Near-miss Management System in your company.	3.48	0.99

Q5 through Q7: 1=strongly disagree; 2=disagree; 3=nor disagree nor agree; 4=agree; 5=strongly agree; Q8: 1=poor; 2=average; 3=good; 4=very good; 5=excellent

The column Mean in Table 1 are sums of answers to particular questions measured on a Likert scale from 1 to 5 divided by the number of answers. The standard deviation in Table 1 indicates dispersion around mean (or average value). For example, the average value of answers for Q5 is 2.52, which is between Likert scale values 2 (disagree) and 3 (nor disagree nor agree) for that question, meaning that respondents generally don't believe that crewmembers onboard their ships report all near-misses they observe. There could be several reasons for not reporting all observed near-misses, including near-miss identification, blame culture, and the complexity of reporting forms. In [3], it was found that lower-ranking crewmembers are not adequately involved in near-miss reporting (less than 3% of the reports done by lower-ranking crewmembers). One way to improve near-miss reporting on ships and include lower-ranking crewmembers in the near-miss management system and safety improvements is to increase near-miss and incident awareness during the education and training of future and active seafarers.

Most of the participants perceive follow up measures received from the company as substantial and applicable (Q6). Studies have shown that not responding and not acting on reported near-misses or incident negatively affects near-miss reporting onboard a ship. However, shore management should continuously improve involvement in the near-miss management system with enhanced communication and instructions to ships and respond to each sent near-miss report.

When asked about their opinion on rating reported near-miss before sending them to the company (Q7), most participants consider it a good practice (Table 1). In that way, processing and investigating near-miss events would be facilitated, focusing on the most critical and high-risk events.

Participating seafarers are considering near-miss management systems on their ships as satisfactory and believe that they are well implemented and improve safety onboard (Q8).

Question (Q9) dealt with the most frequent type of near-miss event. Near-misses connected with Personal Protective Equipment (PPE) were first, with 68.8% of the answers. Other answers included blockage of emergency exits, faulty life-saving and fire-fighting equipment, near-misses during lifeboat drills and others.

In the following questions (Q10), seafarers were offered ten near-miss events types, and they were asked to rate them according to safety importance (from one to ten, where number one is most important to onboard safety, and number ten being least important). According to answers (subject opinion of each participant), near-miss types were rated as follows (Figure 13):

1. Not using/inadequate PPE;
2. Unsecured openings;
3. Oil spill/leak (bunker, cargo, hydraulic oil);
4. Damaged/faulty life-saving equipment;
5. Line handling during mooring/unmooring/tug operation;
6. Fire/explosion hazard;
7. Working without permission;
8. Damaged/faulty fire-fighting equipment;
9. Near collision/grounding/contact;
10. Emergency exit/passage blocked.

According to reported answers, near-misses including PPE are the most common, and seafarers rate them as events of high importance. The least rated near-miss event was blockage of emergency exit, but the surprising fact is that near-collision/grounding/contact is rated as ninth, and it constitutes a severe hazard to human lives, environment and property protection.

According to ABS data [15], the most common types of near-misses recorded in their database were struck by/against, cut, crushed, strain/sprain closely followed by PPE. In their report, out of 200 random records from PPE reports, 89% of PPE near-miss reports were because of PPE not being used, followed by PPE incorrectly used (6%). It seems that PPE usage is still a significant problem onboard ships, although shipping companies developed safety procedures, including the type of PPE to be used during specific job performance.

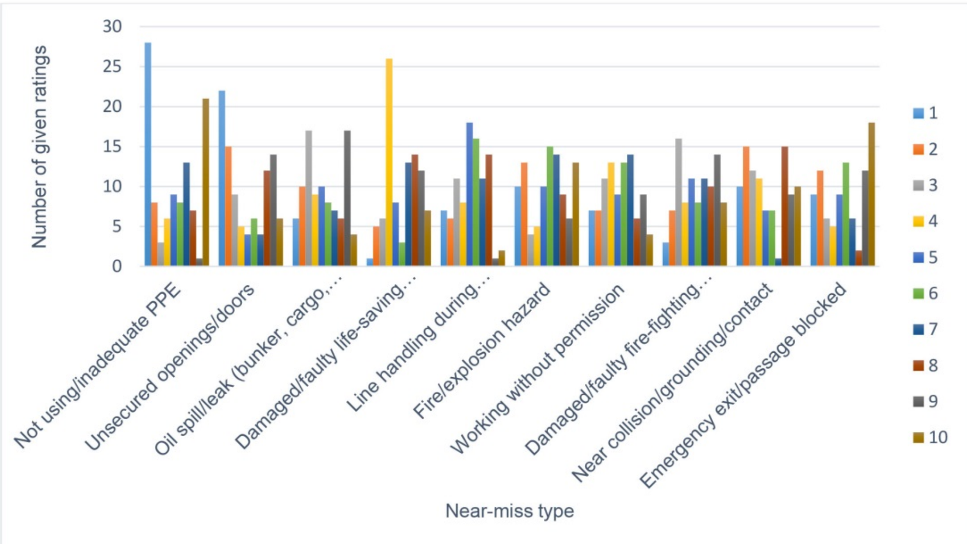


Figure 13 Rating of most important near-miss events

As some shipping companies insist on a specific number of near-miss reports per ship per month, participants were asked if they think there should be a fixed number of reported near-miss per ship per period as a minimum (Q11). Most respondents answered negatively (90%), while only 6% of respondents favoured such demand (Figure 14).

Figure 14 Answers to the question "Do you think that there should be a fixed number of reported Near-misses per vessel?"

In the following question (Q12), participating seafarers were offered four options:

1. One reported Near-miss per crewmember per year.
2. One reported Near-miss per week.
3. Ten reported Near-misses per month.
4. There should not be a fixed number of reported Near-misses per vessel per year as a minimum.

The most favoured option was that there should not be a fixed number of reported Near-misses per vessel per year (88% of respondents). However, a small number of participants (8%) believes that each ship should report one near-miss weekly (Figure 15).

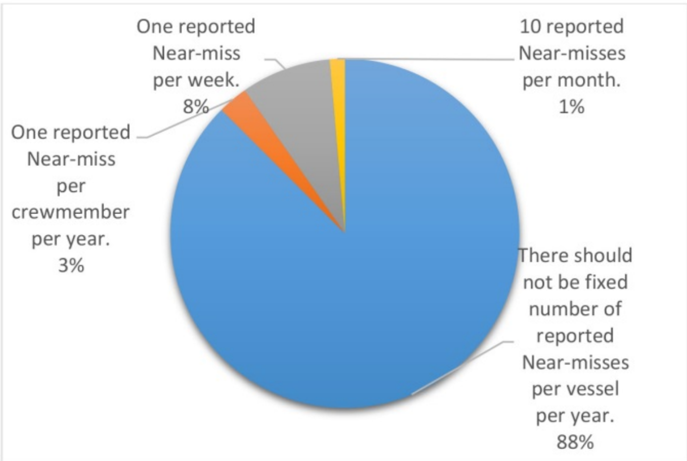


Figure 15 Seafarers' opinion on the number of reported near-misses

It can be argued that a fixed number as a minimum of near-miss reports could introduce false and imagined reports because if there is nothing to report, people could think up near-miss events to fulfil the form. That could be dangerous because false (imagined) reports would end up in databases, wrong conclusions would be drawn, and inadequate corrective measures were implemented. Instead of improving safety in shipping, that kind of report could seriously undermine it.

4. CONCLUSION

From the analysis of survey answers, it can be concluded that surveyed seafarers perceive near-miss management systems on their ships as substantial, and they are mostly satisfied with it. However, many respondents believe that their fellow crewmembers are not reporting all observed near-misses, which happens due to reporting barriers. These barriers need to be bridged to fully use the potential of learning from near-misses and improving safety at sea.

Deck area seems to be the most dangerous area onboard a ship, and near-misses involving PPE are the most frequent and rated as the most important ones. Nevertheless, it can be argued that this type of near-miss event cannot cause severe consequences in most cases, and for instance, near-collision could cause far more severe damage and consequences for human lives, property and environmental protection. Anyhow, seafarers perceive PPE near-misses as significant because of their large number. Safety training and adequate familiarisation of seafarer's onboard ships might reduce these unwanted events to some degree, but implementing adequate safety culture is the key to solving this problem.

Most of the seafarers believe that there should not be a fixed number of near-miss reports. A fixed number of near-miss reports might induce false (imaginary) near-miss reports and misguide researchers to wrong conclusions. If reports only serve to increase their number, conclusions derived from them will be wrong, and real problems will not be tackled.

REFERENCES

[1] Vepsalainen, A.; Lappalainen, J. Utilization of Incident Reporting in the Finnish Maritime Industry; Centre for Maritime Studies University of Turku. Turku, Finland, 2010.
[2] MSC-MEPC.7/Circ.7. Guidance on Near-miss Reporting; International Maritime Organization: London, UK, 2008.
[3] Hasanspahić, N.; Frančić, V.; Vujičić, S.; Maglić, L. Reporting as a Key Element of an Effective Near-Miss Management System in Shipping, Safety 2020, 6, 53; doi:10.3390/safety6040053.
[4] Hasanspahić, N.; Frančić, V.; Vujičić, S.; Maglić, L. Near-Miss Reporting as Seen from Seafarers' Perspective. TransNav, The International Journal on Marine Navigation and Safety of Sea Transportation, in press. DOI: 10.12716/1001.XX.XX.XX.
[5] Gnoni, M.G.; Saleh, J.H. Near-miss management systems and observability-in-depth: Handling safety incidents and accident precursors in light of safety principles. Saf. Sci. 2017, 91, 154–167.
[6] International Maritime Organization: ISM Code, International Safety Management Code and guidelines on implementation of the ISM Code. London, UK (2010).
[7] Craig, B.N.; Papillon, R.; Curry, J.; Zhu, W. Reporting Practices for Close Call (Near Miss) Reporting Systems. In Proceedings of the Offshore Technology Conference, Houston, TX, USA, 5–8 May 2014.
[8] Gnoni, M.; Andriulo, S.; Maggio, G.; Nardone, P. "Lean occupational" safety: An application for a Near-miss Management System design. Saf. Sci. 2013, 53, 96–104.
[9] Meel, A.; Seider, W.D.; Oktem, U. Analysis of Management Actions, Human Behavior, and Process Reliability in Chemical Plants, Part II: Near-Miss Management System Selection. Process Saf. Prog. 2008, 27, 139–144.
[10] Oktem, U.G.; Wong, R.; Oktem, C. Near-Miss Management: Managing the Bottom of the Risk Pyramid. Risk & Regulation. 2010. Available online: http://www.nearmissmgmt.com/Oktem%20Wong%20Oktem%20LSE%202010.pdf (Accessed on 07 May 2021)
[11] Phimister, J.R.; Oktem, U.; Kleindorfer, P.R.; Kunreuther, H. Near-Miss Incident Management in the Chemical Process Industry. Risk Anal. 2003, 23, 445–459.
[12] Rasmussen, H.B.; Drupsteen, L.; Dytreborg, J. Can we use near-miss reports for accident prevention? A study in the oil and gas industry in Denmark. Saf. Sci. Monit. 2013, 17, 1–12.
[13] Lindberg, A.-K.; Hansson, S.O.; Rollenhagen, C. Learning from accidents—What more do we need to know? Saf. Sci. 2010, 48, 714–721.
[14] Oktem, U.G. Near-Miss: A Tool for Integrated Safety, Health, Environmental and Security Management. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.386.9322&rep=rep1&type=pdf (Accessed on 25 April 2021)
[15] American Bureau of Shipping (ABS). Mariner Personal Safety (MPS) Near Miss Statistics. Available online: https://ww2.eagle.org/content/dam/eagle/rules-and-resources/Safety-and-Human-Factors-Design/mariner-personal-safety/mariner-safety-project-resources/MPS%20Near%20Miss%20Statistics.pdf (Accessed on 05 May 2021)

VISION SYSTEM FOR UNMANNED AERIAL VEHICLES DETECTION IN HARBOUR PROTECTION

Stanisław Hożyń
Polish Naval Academy
Gdynia, Poland
E-mail: s.hozyn@amw.gdynia.pl

UDK 004.932: 629.7

Summary

Unmanned Aerial Vehicles (UAVs), often called "drones", pose a threat to strategic marine docking areas, specifically named for this paper's purpose as harbour. One threat that harbours, in the era of rapid development in UAV technology, are exposed to is unlawful aerial surveillance. A more dangerous threat is that UAVs can carry an explosive load to the moored ships. Therefore, protective systems facilitating UAVs detection are being developed. In these systems, there are methods that use techniques that are based on acoustic signals, radio waves, and computer vision. Of the three, computer vision has prompted interest in its research since because of its economical cost as well as its capability to utilise image processing algorithm. Therefore, in this article, a developed vision system facilitating UAVs detection is described. The system's configuration, composed of RGB and thermal cameras, allows for more effective detection through the employment of stereo vision technique and image processing.

Keywords: vision system, unmanned aerial vehicle, harbour protection, image processing, stereo vision

1. INTRODUCTION

Detection of Unmanned aerial vehicles (UAVs) should be one of the prioritised protection measures of any harbour. This is because UAVs' capabilities have become more sophisticated, allowing them more distant missions while carrying heavier loads. Consequently, they can be used in harbour areas to perform surveillance or drop dangerous loads on any of the docked ships. Their small size and high speed, as the perfect weapon for terrorist attacks, makes their detection extremely challenging.

The UAVs detection is possible using various technical solutions including acoustic sensors, radar stations, LIDAR technology and vision systems [6]. One solution, the acoustic sensors, use sound emitted by an object to detect its location. The sensors get activated when they use acoustic arrays consisting of highly sensitive microphones. Using advanced digital signal processing and large number of microphones, the acoustic system enables azimuth and elevation determination of the target in real-time [1], [3]. One flaw of these systems is that although they are able to operate all hours of the day and night, they are susceptible to background noise which can reduce their efficiency [7].

Another solution utilises radar stations developed to scan the space, by emitting electromagnetic waves, to detect threats such as enemy rockets, aeroplanes or UAVs [13]. After reaching the object, the waves are reflected and returned to the receiver. This process allows for the most probable estimation of the object's speed and location [2]. An operating range of a radar amounts to 500 km but can be increased by connecting radars into a wider network. The effectiveness of such systems can work best depending on the size of the object's reflection surface. i.e. the larger the object, the more possible it is to detect it. This makes them less effective in the detection of smaller UAVs that have a less reflective surface. Additionally, electromagnetic noise interference reduces its reliability for accurate UAV detection in harbour areas [15].

A third solution, Lidar, uses ultraviolet or near-infrared light to determine the distance to an object [4]. It is widespread, commonly used in surveying, geodesy, archaeology, geography, and recently in control and navigation of autonomous cars. To operate, it uses active sensors that supply the illumination source. The energy source emits energy, and by measuring the reflected energy, the distance to the object is calculated. The advantage of Lidar, on one hand, is that it is able to work under various weather conditions. The disadvantage, on the other hand, is that other Lidar systems can interfere with its operations.

Other than the previously mentioned solutions, computer vision systems have recently received attention due to numerous optical sensors and several image processing algorithms [12]. The majority of algorithms are based on fundamental image processing techniques, but some of them utilise artificial intelligence to detect, recognise and classify objects [14]. However, the most significant disadvantage of computer vision is its vulnerability to lighting conditions. What is more, they cannot calculate the distance to the object as radars, lidars, or acoustic sensors. To mitigate these drawbacks, a vision system composed of stereo cameras and a thermal camera has been presented in this paper. The main objective of utilising a thermal camera was UAV detection during night-time, while stereo cameras were implemented to calculate the distance to the object.

The present paper describes the developed vision system composed of stereo and thermal cameras. First, the vision system is described. Then, the vision application and the results are presented, and, finally, the conclusions are formulated.

2. VISION SYSTEM

The developed vision system consists of two CAM210 IP Marine Cameras (Fig. 1a) and FLIR M200Compact Pan/Tilt Marine Thermal Camera (Fig. 1b). These cameras are widely used in marine applications due to their compactness and reliability (The technical specifications are presented in Table 1 and Table 2). What is more, they provide video streaming based on the Internet Protocol (IP), which makes them suitable for installation away from the control station (up to 100m). Additionally, CAM210 IP Marine Cameras facilitate operation at low lighting conditions since they are equipped with IR diodes.

a)

b)

Figure 1 a) CAM210 IP Marine Cameras, b) FLIR M200 Marine Thermal Night Vision Camera

Table 1 CAM210 IP Marine Camera specification

CPU	32-bit ARM9 RISC CPU up to 432MHz
Image Sensor	2.0 Megapixel 1/2.8" SONY progressive scan CMOS(Exmor)
Total Pixels	1952(H) x 1116(V) 2.18 Megapixel
Effective Pixels	1944(H) x 1104(V) 2.15 Megapixel
Lens	6.0mm Megapixel Board Lens

Field of View	Diagonal = 63.6 deg +/- 3 deg Horizontal = 33.1 deg +/- 3 deg Vertical = 53.3 deg +/- 3 deg
Video Compression	H.264 High Profile@4.0, MJPEG –Image quality: 3 Steps
Resolution	Up to 1920 x 1080 (Full HD)
Video Streaming	Support multi-stream with H.264, MJPEG Adjustable frame rate CVBR/CBR in H.264
Power Source	DC12V/1.5A, PoE(Power over Ethernet): 802.3af
Power Consumption	Max. 3.3W, Max. 5.3W with IR
Net Weight	900g
Dimensions	83.8mm(W) x 155mm(H) x 178.1mm(D) including Bracket

Table 2 FLIR M200 Marine Thermal Night Vision Camera specification

Detector Type	320 × 240 VOx Microbolometer
Field of View	24° × 18°
Video Refresh Rate	9 Hz
Resolution	320 x 240
Lens	6.0mm Megapixel Board Lens
Power Consumption	15 W (typical) 18 W (max)
Video Output	H264 IP Video stream
Power Requirements	12 or 24 VDC
Pan/Tilt Range	Pan: 360° (continuos), Tilt: +110°, -90°
Size	6.34 (dia.) x 9.03 in (ht.) 161.1 (dia.) x 229.3 mm (ht.)
Weight	6.0 lb (2.7 kg) w/o top-down riser 6.6 lb (3.0 kg) w/ top-down riser

Apart from the cameras, the vision system contains a network switch, a power supply unit and a control station (Fig. 2). The network switch connects all cameras with the control station while the power supply unit powers the cameras and the switch. The control station, which can be located in another place, is powered by the network 230V/50Hz. It is developed using a computer with Intel Core i7-6700HQ CPU 2,6 GHz and 32 GB RAM.

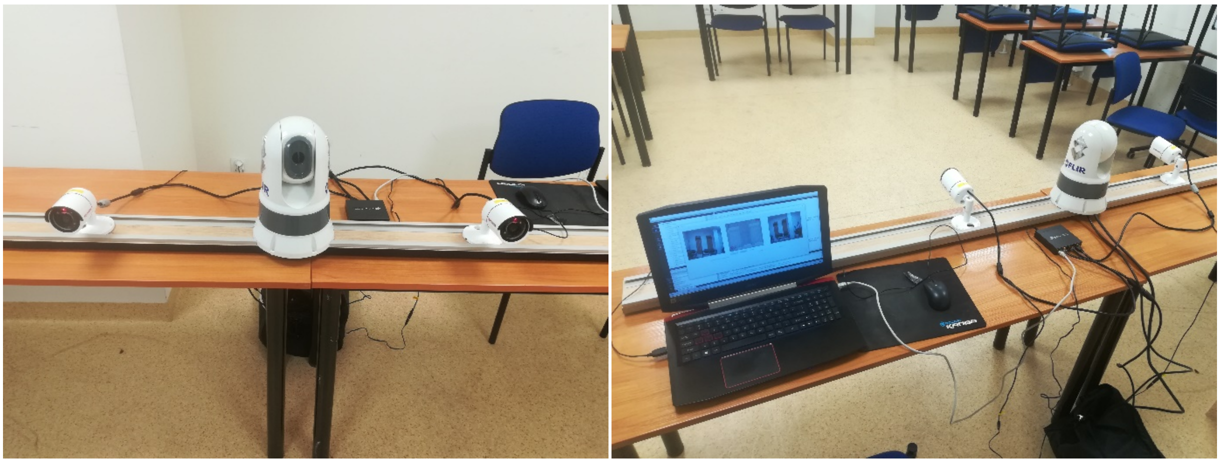


Figure 2 Vision system

The CAM210 IP Marine Cameras constitute a stereo vision system used to obtain depth perception by observing the same scene from different viewpoints. In this process, the following steps are necessary:

- distortion removal
- stereo images rectification
- stereo correspondence
- triangulation, and
- distance calculation.

The distortion removal utilises perspective projection, described by the equations [5]:

$$x = f\frac{X}{Z} \quad , \quad y = f\frac{Y}{Z} \quad , \quad z = f \, , \qquad 1)$$

where X, Y, Z are 3D point coordinates, x, y are coordinates of a point on the image plane and f is the focal length of the camera, equals to the distance between the central point of the camera and the image plane z. Assuming that a CCD array comprises a rectangular grid of photosensitive elements, the x, y coordinates can be transformed into the image plane [8]:

$$\begin{aligned} x &= -(x_{\mathrm{u}} - o_{\mathrm{x}})s_{\mathrm{x}} \\ y &= -(y_{\mathrm{u}} - o_{\mathrm{y}})s_{\mathrm{y}} \end{aligned} , \qquad 2)$$

where: o_{x}, o_y – coordinates of the image centre, s_{x}, x_{y} – the effective size of the pixel (in millimetres) in the horizontal and vertical direction.

Since each optical system introduces geometric distortions, the above-mentioned equations need to be complemented by distortion coefficients, which are commonly divided into radial and tangential ones. The radial distortion displaces image points radially in the image plane and can be approximated by the following equations [9]:

$$\begin{aligned} x_{\mathrm{v}} &= \frac{x_{\mathrm{u}}}{1 + k_1 r^2 + k_2 r^4 + k_5 r^6} \\ y_{\mathrm{v}} &= \frac{y_{\mathrm{u}}}{1 + k_1 r^2 + k_2 r^4 + k_5 r^6} , \\ r^2 &= x_{\mathrm{v}}{}^2 + y_{\mathrm{v}}{}^2 \end{aligned} \qquad 3)$$

where: k_1, k_2, k_5 – intrinsic parameters of camera defining radial distortion, $x_{\mathrm{u}}, y_{\mathrm{u}}$ – ideal pixel coordinates, $x_{\mathrm{v}}, y_{\mathrm{v}}$ – distorted coordinates.

The tangential distortion is created by the not collinear surface of the lens and usually defined in the following form [9]:

$$\begin{aligned} y_{\mathrm{t}} &= k_3(r^2 + 2y_{\mathrm{u}}) + 2k_4 x_{\mathrm{u}} y_{\mathrm{u}} \\ x_{\mathrm{t}} &= 2k_3 x_{\mathrm{u}} y_{\mathrm{u}} + k_4(r^2 + 2x_{\mathrm{u}}^2) \end{aligned} , \qquad 4)$$

where: k_3, k_4 – tangential distortion, $x_{\mathrm{t}}, y_{\mathrm{t}}$ – distorted coordinates.

After including lens distortion, the coordinates of the undistorted points ($x_{\mathrm{d}}, y_{\mathrm{d}}$) are approximated as follows [9]:

$$\begin{aligned} x_{\mathrm{d}} &= x_{\mathrm{v}} + x_{\mathrm{t}} \\ y_{\mathrm{d}} &= y_{\mathrm{v}} + y_{\mathrm{t}} \end{aligned} . \qquad 5)$$

Stereo images rectification constitutes mathematical transformation that makes epipolar lines in both images collinear and parallel to the images scanning lines. The stereo vision system, which meets these requirements, is called standard or canonical stereo setups (see Fig. 3).

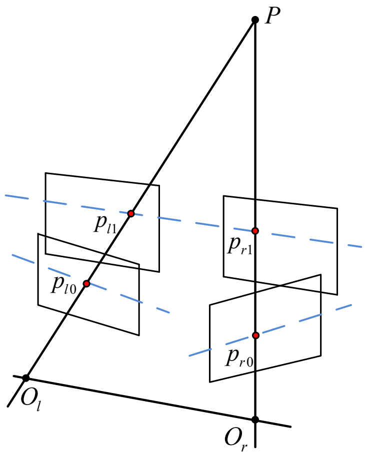


Figure 3 Stereo images rectification

The rectification process includes the following transformations:

– rotation of the left and the right image to move epipolar points to infinity, defined by the matrix $\boldsymbol{Q}$; and
– rotation of the right image by a matrix $\boldsymbol{R}$.

The distortion coefficients, as well as rectification matrices, can be determined using the calibration procedure. The most convenient way to perform this procedure is to use the methods implemented into the OpenCV libraries. These methods utilise a chessboard pattern presented in front of the stereo cameras. In practice, 10 to 20 chessboard images taken from different viewpoints are needed to obtained calibration parameters. The developed vision system was equipped with a calibration module (Fig. 4) which facilitates the automatic calibration process.

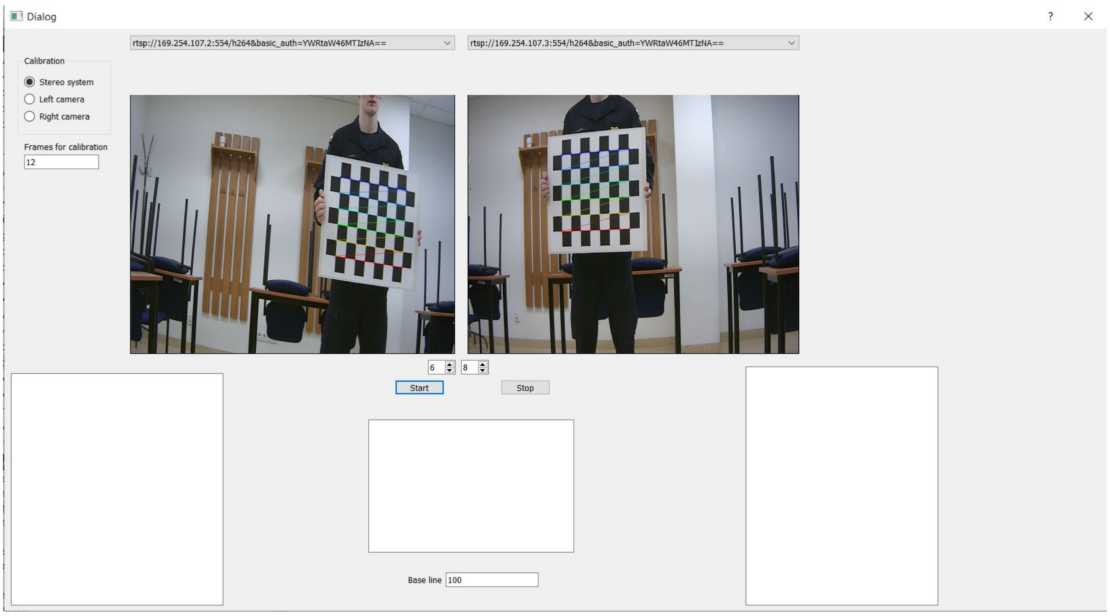


Figure 4 Camera calibration module

In the developed solution, the stereo correspondence is used to calculate the UAV's position against the vision system. For this purpose, the UAV is marked in the left image, and the corresponding region in the right image is determined by applying a block matching technique. The block matching technique compares the defined area with the correspondence region located on the same epipolar line in the right image using the following formula [10]:

$$R(x,y)=\frac{\sum_{x',y'}(T(x',y')-I(x+x',y+y'))^2}{\sqrt{\sum_{x',y'}T(x',y')^2\cdot\sum_{x',y'}I(x+x',y+y')^2}}, \quad 6)$$

where $R(x,y)$ is the result of the comparison, T is the UAV area in the left image and I is the corresponding area in the right image laying on the same epipolar line. Consequently, x' is equal x_R in Fig. 4, while y' is equal to the height of the UAV area in the left image. The best matching is obtained for the lowest value of $R(x,y)$.

The triangulation task is simplified after distortion removal and rectification. In this case, the geometry of a stereo setup can be graphically represented, as shown in Fig. 5.

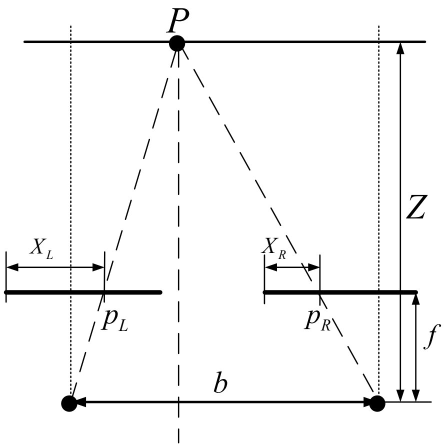


Figure 5 Canonical stereo setup

In this case, the distance to the 3D point can be calculated using the following formula [11]:

$$Z=\frac{bf}{D_x(\boldsymbol{p}_l,\boldsymbol{p}_r)}, \quad 7)$$

where Z is the distance from the point $\boldsymbol{P}$, b is the distance between the cameras, and f is the camera focal length. $D_x(\boldsymbol{p}_l,\boldsymbol{p}_r)$ denotes horizontal disparity and is determined as $D_x(\boldsymbol{p}_l,\boldsymbol{p}_r)=x_L-x_R$ whereby x_L, x_R are horizontal coordinates of the points $\boldsymbol{p}_l$ and $\boldsymbol{p}_r$ on the image planes.

The computer vision algorithm implemented into the vision system is presented in the figure below.

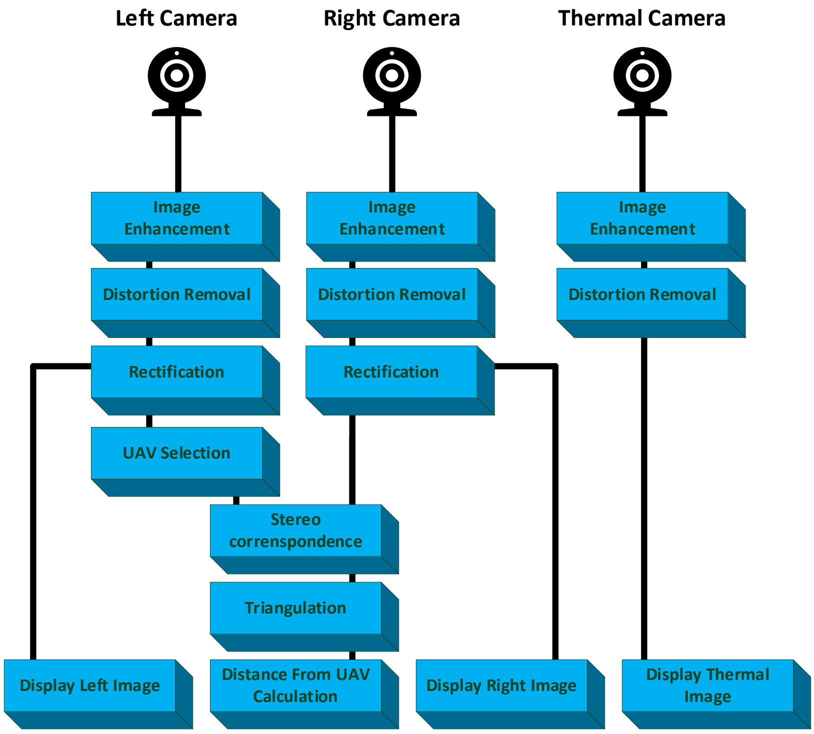


Figure 6 Computer vision algorithm

In the first step, the image enhancement is implemented. It consists of mean filtering (5x5 window) and image normalisation. Mean filtering allows removing high frequency from the image caused by cameras' optical systems while image normalisation changes the range of pixel intensity values from 0 to 255. These techniques give the best results in view of the stereo correspondence method. The next step performs distortion removal, which is essential for triangulation's accuracy. Stereo images are next rectified, and UAV selection can be completed in the left image. When an operator marks the UAV area in the left image, the stereo correspondence, triangulation and distance from UAV calculation are fulfilled. Finally, left, right and thermal images are displayed.

3. VISION APPLICATION

A computer application, which was employed to control the vision system, was developed using C++ programming language and Qt and OpenCV libraries. The advantage of this solution is that it is independent from operational systems and is equipped with a Graphical User Interface (GUI), presented below.

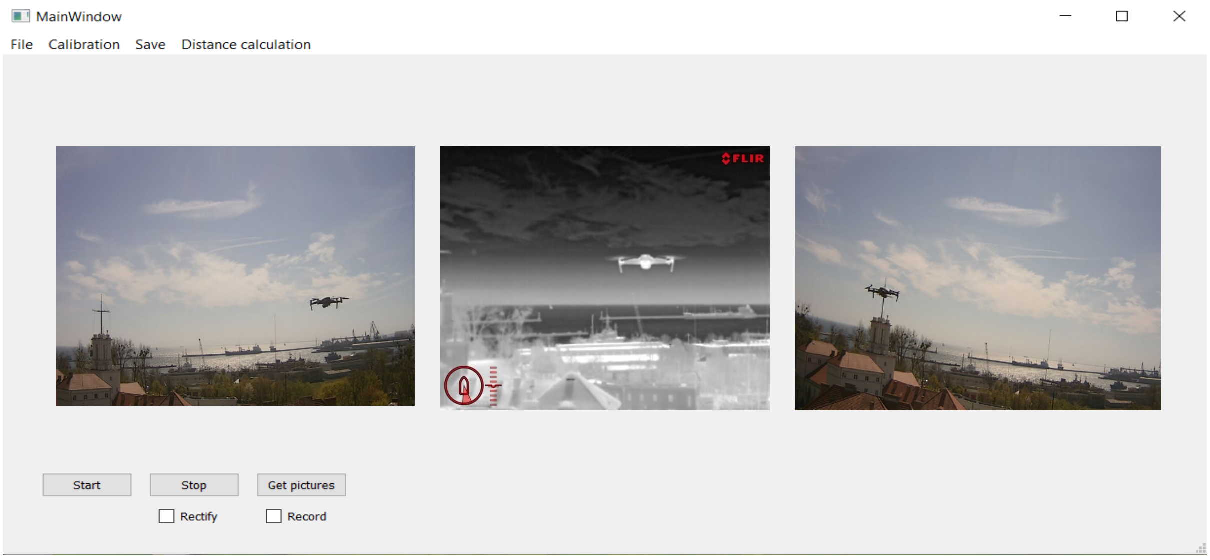


Figure 7 Graphical user interface

The user interface allows the following operations:

- connection between the cameras and the control station;
- displaying images from the cameras;
- saving images to files;
- marking UAV's area in the left image; and
- distance from a UAV calculation using the triangulation method.

In order to ensure fast image processing, the application is divided into three threads; each of them is running on a different core of a processor. The first thread is responsible for images acquisition from the cameras. The second thread enables image processing whereas the third one is responsible for displaying images and writing them to the files. The acquired images are stored in a common memory of the application, accessible for all three threads. The first thread's function is to gather images from the cameras and writes them into the common memory. The second thread's purpose is to process images saved in the common memory. The third thread works independently and displays the processed images at a frequency equals to 25 Hz. Due to this speed ratio, when the most recent images have not been processed yet, the previous ones are displayed in the windows. This allows an operator to use the *Distance calculation* in the Tool Menu, as the best option to calculate the distance from any UAV. As a result, the displaying of new images stops, and the UAV's area in the left image can be selected. For the selected area, the corresponding region in the right image is determined and shown in the image. The distance from the UAV is calculated based on the stereo correspondence technique and displayed. The structure of the application is presented graphically in Figure 8.

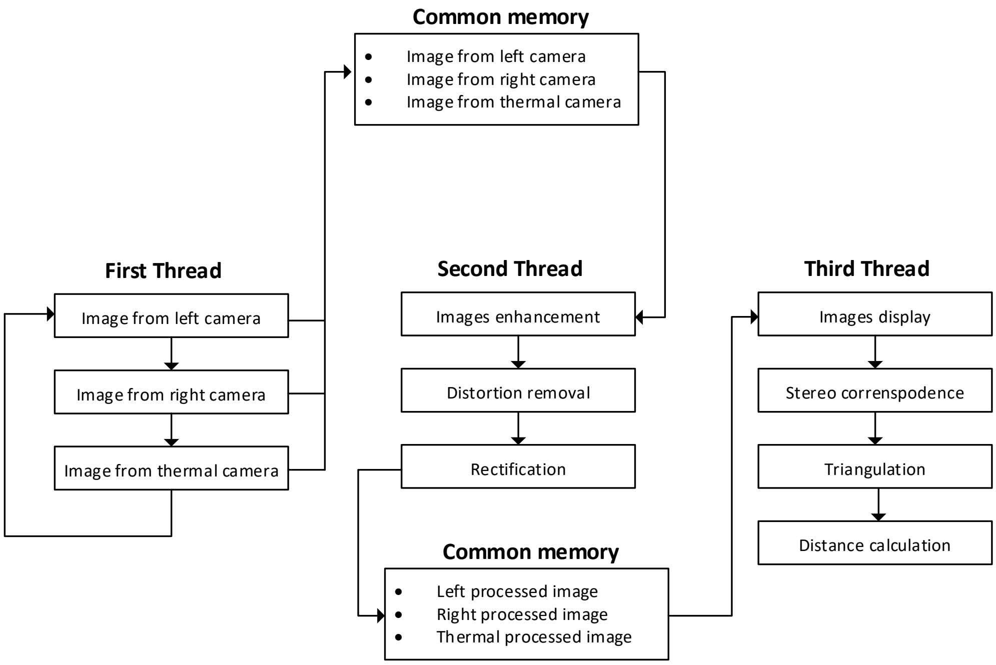


Figure 8 Graphical user interface

4. RESULTS

As mentioned previously, our work aimed to construct a vision system that facilitates operation at low light conditions and enables distance to UAV calculation. The obtained pictures for different lighting conditions are presented in Figure 9.

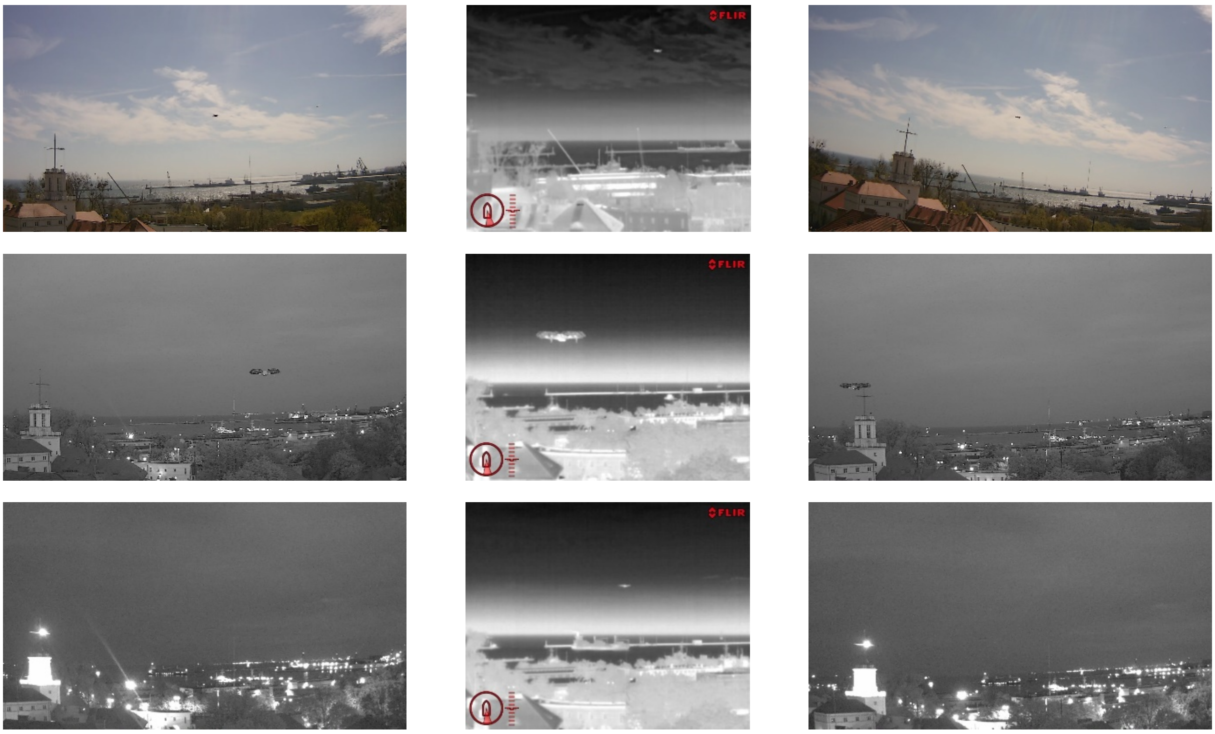


Figure 9 Images obtained for different lighting conditions

Apart from facilitating operation under different lighting conditions, the devised system was developed to calculate the distance to the UAV. In this process, an operator marks the UAV area in the left image, and the corresponding region in the right image is estimated using the block matching technique (Figure 10).

Figure 10 Block matching correspondence

To access the accuracy of the measurement, the GPS was mounted in the UAV. The GPS data obtained during tests were compared with the distances calculated using stereo cameras. The obtained results are presented in Figure 11.

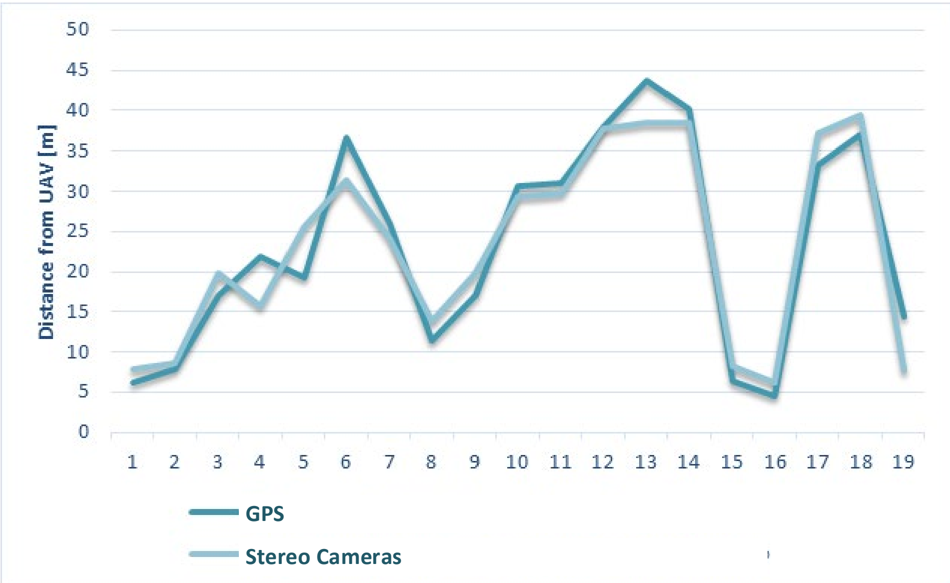


Figure 11 Distance from the UAV

These results demonstrate that using the stereo cameras, similar results compared to GSP data are obtained.

5. CONCLUSION

In summary, the paper presents the vision system facilitating UAV detection under different lighting conditions. The proposed solution also allows determination of distance from the UAV. Its accuracy was assessed by comparison with GPS data. It indicates that measurement performed using stereo vision cameras gives similar results to the GPS data.

The developed vision system gives great opportunities in the area of image processing. Therefore, future work will focus on object detection and tracking algorithms that can facilitate the automatic operation of the developed system.

Acknowledgment

The paper is funded by a Research Grant of the Polish Ministry of Defence entitled "Vision system for object detection and tracking in the marine environment".

REFERENCES

[1] Busset, J. *et al.*, "Detection and tracking of drones using advanced acoustic cameras," 2015, p. 96470F.
[2] Coluccia, A., Parisi, G., and Fascista, A., "Detection and Classification of Multirotor Drones in Radar Sensor Networks: A Review," *Sensors*, vol. 20, no. 15, p. 4172, Jul. 2020.
[3] Dumitrescu, C., Minea, M., Costea, I. M., Cosmin Chiva, I., and Semenescu, A., "Development of an Acoustic System for UAV Detection," *Sensors*, vol. 20, no. 17, p. 4870, Aug. 2020.
[4] Hammer, M., Hebel, M., Arens, M., and Laurenzis, M., "Lidar-based detection and tracking of small UAVs," in *Emerging Imaging and Sensing Technologies for Security and Defence III; and Unmanned Sensors, Systems, and Countermeasures*, 2018, p. 35.
[5] Hożyń, S., "Vision-Based Modelling and Control of Small Underwater Vehicles," in *Advances in Intelligent Systems and Computing*, 2020, pp. 1553–1564.
[6] Hożyń, S. and Przybysz, M., "Detection of Unmanned Aerial Vehicles Using Computer Vision Methods: A Comparative Analysis," *Scientific Journal of Polish Naval Academy*, vol. 220–221, no. 1–2, pp. 5–13, Jun. 2020.
[7] Hożyń, S. and Wierszyło, M., "Tracking of Unmanned Aerial Vehicles Using Computer Vision Methods: A Comparative Analysis," *Scientific Journal of Polish Naval Academy*, vol. 223, no. 4, pp. 39–51, Dec. 2020.
[8] Hożyń, S. and Żak, B., "Moving Object Detection and Localization Using Stereo Vision System," in *Advances in Intelligent Systems and Computing*, vol. 317, 2015, pp. 417–424.
[9] Hożyń, S. and Żak, B., "Distance Measurement Using a Stereo Vision System," *Solid State Phenomena*, vol. 196, pp. 189–197, Feb. 2013.
[10] Hożyń, S. and Żak, B., "Local image features matching for real-time seabed tracking applications," *Journal of Marine Engineering and Technology*, 2017.
[11] Hożyń, S. and Żak, B., "Stereoscopic Technique for a Motion Parameter Determination of Remotely Operated Vehicles," in *Advances in Intelligent Systems and Computing*, vol. 414, 2016, pp. 263–283.
[12] Lai, Y.-C. and Huang, Z.-Y., "Detection of a Moving UAV Based on Deep Learning-Based Distance Estimation," *Remote Sensing*, vol. 12, no. 18, p. 3035, Sep. 2020.
[13] Riabukha, V. P., "Radar Surveillance of Unmanned Aerial Vehicles (Review)," *Radioelectronics and Communications Systems*, vol. 63, no. 11, pp. 561–573, Nov. 2020.
[14] Saqib, M., Daud Khan, S., Sharma, N., and Blumenstein, M., "A study on detecting drones using deep convolutional neural networks," in *2017 14th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS)*, 2017, pp. 1–5.
[15] Stateczny, A., Kazimierski, W., Burdziakowski, P., Motyl, W., and Wisniewska, M., "Shore construction detection by automotive radar for the needs of autonomous surface vehicle navigation," *ISPRS International Journal of Geo-Information*, vol. 8, no. 2, 2019.

THE DETERMINATION OF CORROSION RATE THROUGH OXYGEN CONTENT IN A Cu-Al-Ni ALLOY UNDER THE INFLUENCE OF SEAWATER [1]

Špiro Ivošević
University of Montenegro, Faculty of Maritime Studies Kotor
Kotor, Montenegro
E-mail: spiroi@ucg.ac.me

Nataša Kovač
University of Donja Gorica, Faculty of Applied Sciences
Podgorica, Montenegro
E-mail: natasa.kovac@udg.edu.me

Gyöngyi Vastag
University of Novi Sad, Faculty of Technical Sciences
Novi Sad, Serbia
E-mail: djendji.vastag@dh.uns.ac.rs

UDK 620.193.2
551.3.053

Summary

The application of new materials in different industries requires the testing of those materials in laboratories and real environmental conditions in which the materials could be used. The application of shape memory materials in maritime industry, due to complex conditions of the marine environment, predominantly requires practical research on physical and chemical changes of alloys as well on corrosion rates and the intensity of material degradation. So far, numerous studies analyzed the corrosion rate of metallic materials through percentage or dimensional reduction of material thickness, assuming the linear and nonlinear models of corrosion rate. This paper analyzes the changes in the chemical composition of a Cu-Al-Ni alloy in the atmosphere and in the changeable conditions of the sea surface and seawater. The changes in the chemical composition of the alloys after 6 and 12 months of exposure were monitored by means of Energy Dispersive Spectrometer (EDS). Considering the changes in oxygen content during 6 and 12 months of exposure, the research analyzed a linear model of the development of corrosion rate based on the increase in the oxygen content in the alloy. Results showed that there is a correlation between the percentage of oxygen and the time of exposure of the sample to the marine environment - the percentage of oxygen is the highest under the influence of the sea, slightly lower under the influence of tides and the lowest percentage increase in oxygen occurred under the influence of the air.

Keywords: corrosion, oxygen, shape memory alloy, seawater, atmosphere

1. INTRODUCTION

Rapid industrial development over the previous decades has not only enhanced the research of traditional materials, but has also contributed to the discovery of new, smart materials. Smart materials can change their shape under various influences (temperature, stress, moisture, etc.). Shape memory materials (SMM) have two different phases. Upon martensitic and austenitic transformation (martensite at low and austenite at

[1] Funding: The research was funded by the EUREKA PROGRAM PROCHA-SMA E!13080, the Ministry of Science, the Republic of Montenegro, and bilateral projects Serbia – Montenegro (BI-ME/18-20-024).

high temperature) there is a change in the crystal structure of materials - superelasticity, one-way memory effect, two-way memory effect or damping appear under external influences [1].

The most important shape memory alloys are based on Cu, Al, and Ni and are widely distributed in the combinations of binary, ternary and quaternary systems in order to ensure better characteristics of alloys (mechanical and chemical characteristics, biocompatibility, corrosion resistance) [2]. The production processes of alloys have a dominant influence on the composition of alloys and their properties, especially on grain size.

Up to now, some processing routines like casting, powder metallurgy route, rapid solidification processing, and spray casting have been the most frequent production techniques [3]. However, continuous casting technique has recently become one of the most frequent technologies for the production of Shape memory Alloys (SMAs).

Shape memory materials are applied in medicine, robotics, aviation, automotive and other industries [4, 5]. The application of smart materials is becoming more common in maritime industry [6] e.g., the application to fixed marine structures, different vessels, and underwater vehicles are some of the uses of shape memory alloys that are equally applicable at sea depths and surfaces.

Exposure to different marine and atmospheric conditions requires the research on smart materials in laboratories and real conditions with the aim of defining the material behavior. Corrosion resistance, change in chemical compositions, biocorrosion, the examination of corrosion rates of different physical forms of corrosion are just some of the analyses that should be conducted in order to determine potential applications and behavior of alloys in the marine environment [2, 3].

This study investigates the changes in the chemical composition of the Cu-Al-Ni alloy that was exposed to various influences of the sea and atmosphere for 6 and 12 months. Based on the changes in the oxygen content of the alloy, the research relies on a linear model of the occurrence of oxygen in the alloy, which is considered the main cause of corrosion. The second chapter analyzes the corrosion of the Cu-Al-Ni alloy. Materials and methods necessary for the analysis of the database as well as the linear model of corrosion development are presented in the third chapter. The fourth chapter presents the results of the research while the fifth chapter provides concluding remarks.

2. CORROSION OF Cu ALLOY

Corrosion is an electrochemical process that occurs on metallic materials. There are various forms of corrosion, such as general, pitting, stress, etc. Degradation of materials caused by electrochemical corrosion results primarily in the separation of anode oxidation processes of metals from cathode sites (reduction of dissolved oxygen or other corrosive agents).

The monitoring of the corrosion of copper, as the main component of Cu-Al-Ni alloy, requires the consideration of the following facts: in a corrosive medium (in the absence of complexing ligands), the anodic dissolution of copper happens as a two-step reaction:

$$Cu \rightarrow Cu^{+}_{ads} + e^{-} \quad (1)$$

$$Cu^{+}_{ads} \rightarrow Cu^{2+} + e^{-} \quad (2)$$

whereby Cu^{+}_{ads} is an adsorbed species at copper surface, which is not diffused into bulk solution.

The reduction of oxygen in a neutral solution happens as a cathodic reaction:

$$O_2(g) + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \quad (3)$$

The resulting copper ions (mostly Cu^{+}) react with hydroxide ions in a secondary chemical reaction during which mainly Cu_2O is formed. Cu_2O is well-absorbed on copper surface, thus protecting the surface from further corrosion. During longer exposure, copper surface can also contain salts or other oxides such as: CuO, $Cu(OH)_2$, Cu_2O_3, etc.

In chloride-containing medium (seawater), electrochemical corrosion of copper can be represented as:

$$Cu + Cl^- \rightarrow CuCl_{ads} + e^- \quad (4)$$

$$CuCl_{ads} + Cl^- \rightarrow CuCl_2^- \quad (5)$$

Cu_2O is, nevertheless, the main corrosion product of copper, because copper-chloride complexes, formed in the hydrolysis reaction, typically form Cu_2O again.

$$2CuCl_2^- + H_2O \rightarrow Cu_2O + 2H^+ + 4Cl^- \quad (6)$$

High concentration of chloride ions along with the prolonged exposure of metals to corrosive environment lead to the formation to higher-order copper-chloride complexes like $CuCl_3^-$, or $CuCl_4^{2-}$. These complexes remain stable over a longer period of time and are dangerous because their presence leads to the pitting corrosion of copper.

On the other hand, corrosion can occur over time due to internal factors (chemical composition, metal resistance, and surface treatment) and external factors (environmental conditions, the intensity of operational activities, etc.) [7]. Based on extensive research in laboratories and real conditions, now there are numerous linear and nonlinear models of corrosion development [8]. Corrosion rate is calculated in mm or nm of material thickness reduction [9, 10, 11, 12, 13, 14] or as the percentage of wear [15]. Considering a developed linear corrosion model of the Cu-Al-Ni alloy and the fact that the percentage of wear can be the basis for the development of a linear model [15], this research tested a linear model of corrosion development based on the percentage increase in oxygen content over 6 and 12 months.

3. MATERIALS AND METHODS

This research is based on a real experiment that included the monitoring of the behavior of a Cu-Al-Ni shape memory alloy in different types of the marine environment. Six rod-shaped alloys, whose length was 100 mm, and the diameter was 8.3 mm, were placed in the atmosphere 3 m above the sea surface, in tidal zone, and in the sea at the depth of 3 m.

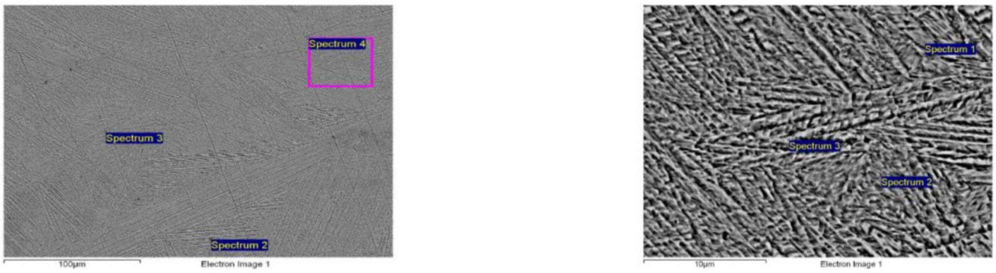
The research was conducted between August 2018 and August 2019. The parameters of seawater on the sea surface (temperature and salinity) were measured by the Institute of Biology, the University of Montenegro. The lowest temperature was measured in February 2019 (11.7 ^{0}C on the sea surface and 14.00 ^{0}C at the depth of 5m), while the highest temperature was measured in August 2019 (25.00 ^{0}C on the sea surface and 19.2 ^{0}C at the depth of 5m). The lowest salinity was measured in December 2018 (14 ‰ on the sea surface and 27.6 ‰ at the depth of 5m) and the highest in August 2019 (37.7 ‰ on the sea surface and 39.4 ‰ at the depth of 5m). The previously published data [7] show a very small difference between the temperatures on the sea surface and at the depth of 5m, while a more significant difference was noted in salinity on the sea surface and in shallow water, mostly during the rainy season [16].

On the basis of the previously published data, the average of minimum air temperatures varied between 6 ^{0}C and 7 ^{0}C in January and the average of maximum air temperatures was between 24 ^{0}C and 25 ^{0}C in August. Humidity varied between 63% (July and August) and 78% (January) [7]. This study analyzed the changes in the composition of alloys caused by external environmental influences but did not analyze the influence of environmental parameters on corrosion.

For the purposes of this study, a semi-quantitative analysis determined the chemical composition of the samples whose corrosion emerged after 6 and 12 months of exposure. Microchemical analysis was performed by means of Emission Scanning Electron Microscope which contains an Energy Dispersive Spectrometer (EDS) - Oxford INCA 350 [14].

3.1. Data Collection for the Analysis of Cu-Al-Ni Alloy

Before testing, the basic samples were scanned by Energy-dispersive X-ray spectroscopy (EDX). Figure 1 and Table 1 show the view of a sample and the chemical composition of the four samples.



a) b)

Figure 1 The view of a sample before testing in different types of the environment, a) the center of Cu-Al-Ni, sample 1 (100µm), b) the center of Cu-Al-Ni, sample 4 (10µm)

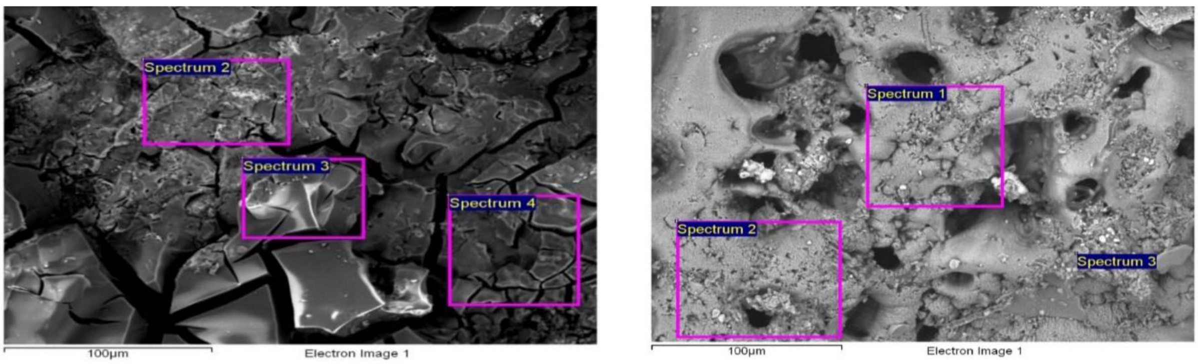
Table 1 The chemical compositions of four Cu-Al-Ni samples before testing

Element	Al	Ni	Cu	Total
Sample mean 1	11.64	4.22	84.14	100.00
Sample mean 2	12.14	4.15	83.71	100.00
Sample mean 3	12.20	3.99	83.81	100.00
Sample mean 4	12.31	3.80	83.89	100.00
MEAN OF ALL	12.07	4.04	83.89	100.00

The analysis of the samples included metallographic sample preparation, material testing by optical microscope, microstructure overview, micro hardness, the Inductively Coupled Plasma (ICP) and X-ray fluorescence (XRF) analysis [17]. Afterwards, sixth Cu-Al-Ni samples produced by continuous casting in the shape of rods were used as test samples in corrosive, marine environment.

As previously indicated, data analysis was conducted through the systematization of the data from the EDX analysis in order to obtain the distribution of the chemical compositions of metals. The EDX analysis focused on the samples of the Cu-Al-Ni alloy found in three different environmental zones. The EDX semi-quantitative analysis determined the content of elements on the surface of the samples examined.

According to Table 1, Cu, Al and Ni comprise 100% of the chemical composition of the alloy**.** Due to a long exposure to different types of the environment for 6 and 12 months, the differences in the appearance of samples (Figure 2) and chemical composition of the alloy (Table 2) were detected by the EDX method.



a) b)

Figure 2 The view of a sample, a) the view of Cu-Al-Ni alloy after 6 months in seawater, b) the view of Cu-Al-Ni alloy after 12 months in seawater

Table 2.The chemical composition of a sample after 12 months of exposure to seawater

Spectrum	In stats.	C	O	Mg	Al	Si	Cl	Ca	Total
Spectrum 1	Yes	26.08	50.61	0.39	0.74	1.23	0.54	20.41	100
Spectrum 2	Yes	29.26	49.6	1	1.43	2.37	1.28	15.06	100
Spectrum 3	Yes	19.52	39.53	1.18	2.77	31.15	2.65	3.2	100
Mean		24.95	46.58	0.86	1.65	11.58	1.49	12.89	100
Std. deviation		4.97	6.12	0.41	1.03	16.95	1.07	8.81	
Max.		29.26	50.61	1.18	2.77	31.15	2.65	20.41	
Min.		19.52	39.53	0.39	0.74	1.23	0.54	3.2	

According to Table 2, after 12 months of exposure to seawater, the chemical composition shows the influence of chloride, oxygen, and other elements. As mentioned in the introduction, the corrosion of copper happens mainly through copper oxide formation in the environment investigated, during the time of exposure. Therefore, the data on oxygen content was collected after 6 and 12 months from the three zones analyzed (air, tide, sea). In Figure 3, the ordinal numbers of the samples are represented on the x-axis, while the ordinate represents the corresponding percentage amounts of oxygen.

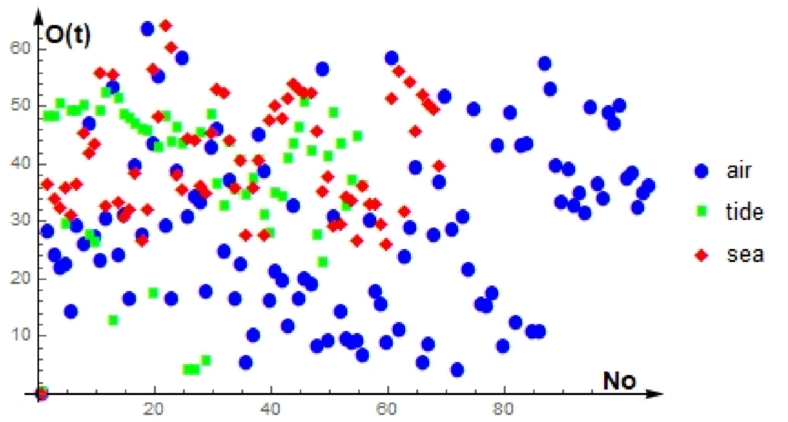


Figure 3 Percentage of oxygen in samples exposed to three marine zones

3.2. Methods

The percentage of oxygen in the structure of Cu-Al-Ni alloys was analyzed on the basis of the linear dependence of the oxygen growth in alloys on the influence of oxygen on corrosive processes. Before the exploitation of alloy samples or their exposure to environmental influences, the percentage of oxygen was considered zero (Table 1). The increase in the duration of exposure to the environment corresponded to the increase in the percentage of oxygen (Table 2). The emergence of oxygen is influenced by various factors which accelerate corrosion process [7]. However, this paper observes only the functional dependence of oxygen percentage on the time of exposure of the sample to one of the three types of the environment: air, tide, seawater. The assumption was that the percentage of oxygen changes at a constant rate, so the corresponding model can be represented as:

$$O(t) = c * t, \qquad 7)$$

whereby $t \geq 0$ represents the time elapsed since the beginning of the experiment (expressed in months), $O(t)$ is the percentage of oxygen of the Cu-Al-Ni alloy in time t , while the coefficient c represents the change in the percentage of oxygen at a monthly level (expressed as percentage per month). As the experiment was conducted in three different types of the marine environment and based on empirical data, there were three models of percentage changes in the amount of oxygen. More precisely, three models were formed to interpret the percentage of oxygen increase in the Cu-Al-Ni alloy. These models were labeled as $O_A(t)$, $O_T(t)$, and $O_S(t)$, for the influence of air, tide, and sea, respectively.

According to the initial assumption, at the beginning of the experiment oxygen content was 0 for all samples, which can be represented as $O_A(0) = O_T(0) = O_S(0) = 0$. After 6 and 12 months of exposure, the percentage of oxygen in each of the 6 samples observed, and for each type of the marine environment $(O_A(t), O_T(t), O_S(t), t = 6, 12)$ was measured by the EDX method. In this way, an empirical database was formed for further use in statistical analysis.

4. RESULTS

In the following statistical analysis, the percentage of oxygen in samples is considered a dependent variable, while the exposure time of the sample to the environmental influences is considered an independent variable. The aim of the statistical analysis is to establish the functional dependence of the percentage of oxygen on the time of exposure of the sample to one of the three external influences: air, tide, or sea.

As already indicated, the percentage of oxygen on the surface of samples was zero at the beginning of exploitation, which was the initial assumption of the research. Therefore, this statistical analysis is based on the fitting of a linear model without an intercept constant.

The fitted linear model is represented by equations (8) - (10). These models are graphically presented in Figures (4) - (6) along with the related 95% confidence intervals.

$$O_A(t) = 2.51067 * t \qquad 8)$$

$$O_T(t) = 3.38402 * t \qquad 9)$$

$$O_S(t) = 3.99907 * t \qquad 10)$$

Linear functions equation $O_A(t)$, $O_T(t)$, $O_S(t)$, were obtained by minimizing the difference between the empirical value of the percentage of oxygen and the estimated value of a linear function $O(t)$ for each observed value of elapsed time (t) and for each type of the marine environment examined.

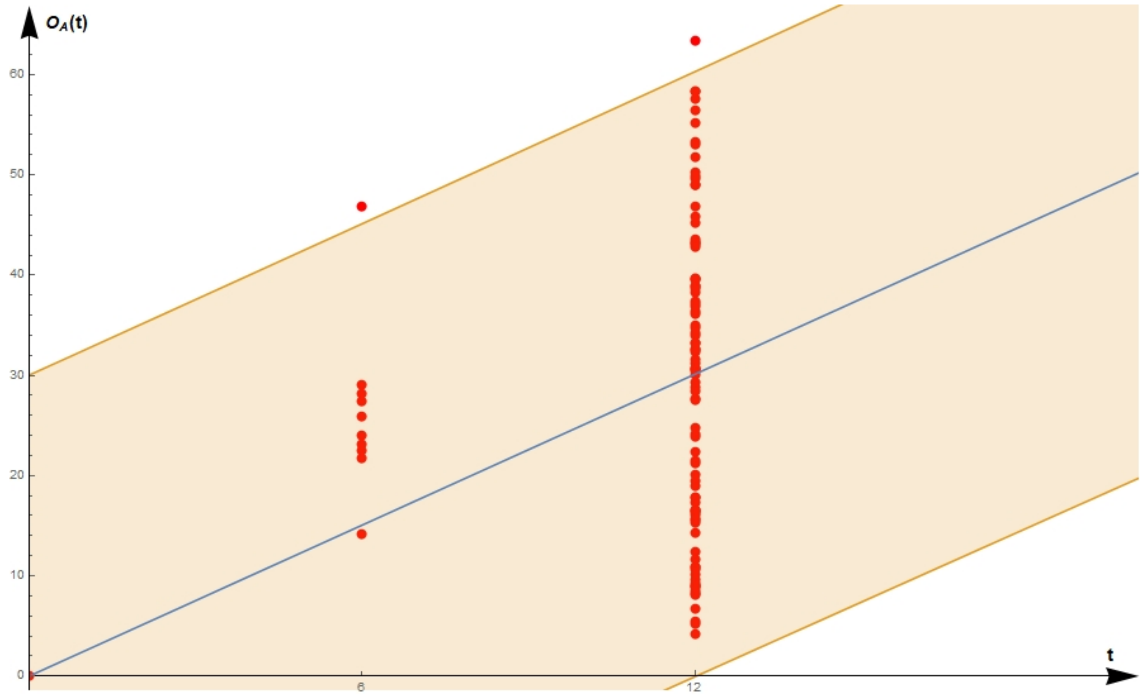


Figure 4 A linear model of the change in the percentage of oxygen under the influence of the air

The three graphs in Figures (4) - (6) show a tendency for an increase in the percentage of oxygen, which corresponds to the increase in the duration of exposure to the air, tides, and sea. As expected, the fastest increase in the percentage of oxygen in observed under the influence of the sea, a slightly slower increase is noted in tidal zone, while the slowest increase is noted under the influence of the air. According to Figures (4) - (6), all linear functions pass through the origin, which is a consequence of the initial assumption that the primary percentage of oxygen equaled zero.

Based on the coefficients of linear terms in fitted equations (8) - (10), it can be concluded that the monthly percentage of oxygen in the sample increased under the influence of air by approximately 2.51% and by 3.38% under the influence of tides. The sea influenced the increase in oxygen percentage by approximately 3.99% on a monthly basis.

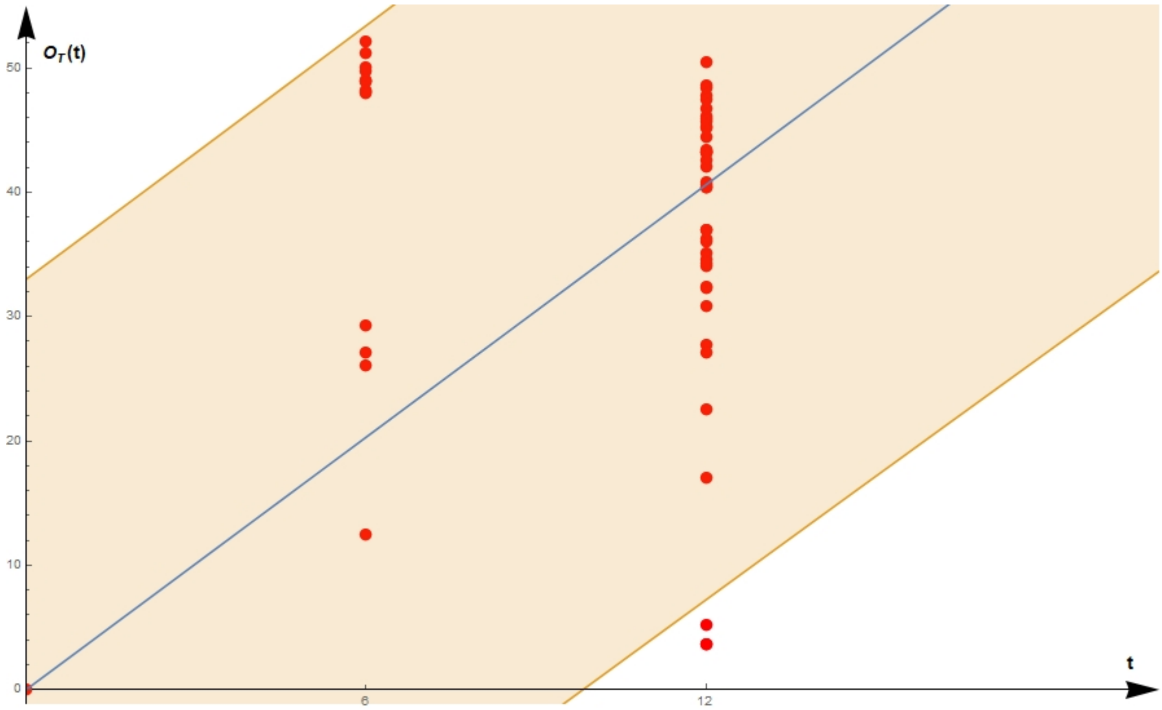


Figure 5 A linear model of the change in the percentage of oxygen under tidal influence

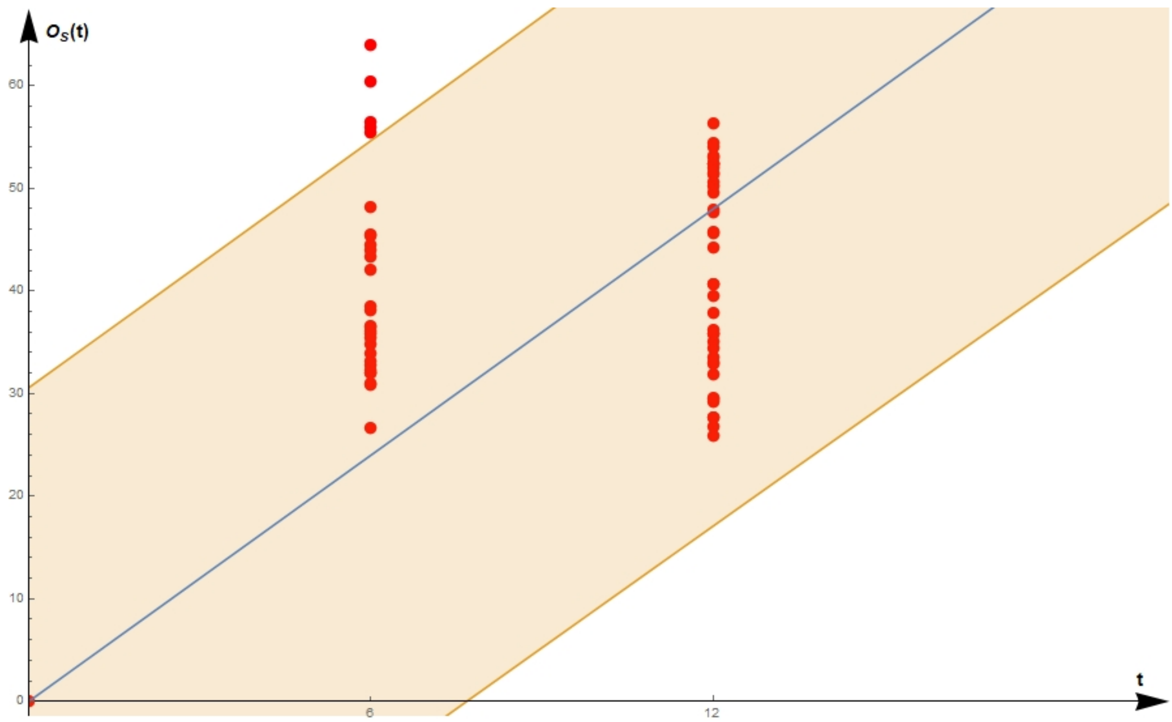


Figure 6 A linear model of the change in the percentage of oxygen under the influence of the sea

Table 3 shows the analysis of variance related to the three models represented by equations (8) - (10). The column labeled as df for each of the three types of the marine environment observed, represents the number of independent variables (in this statistical analysis and for the three models this value is 1). The df residual equals the difference between the number of samples and the number of independent variables. The SS column shows the value of the sum of squares, while the MS column shows the mean of the sum of squares. The fourth column presents the F-statistic calculated as the quotient of Regression MS and Residual MS. Such statistics is used to test the null hypothesis that the coefficient of the independent variable t essentially equals zero. P-value is shown in the last column. The null hypothesis was tested with a significance level $\alpha = 0.05$.

Table 3 The ANOVA table

Air	df	SS	MS	F-statistic	p-value
parameter	1	87593.2	87593.2	381.899	$1.34551*10^{-36}$
Residual	104	23853.6	229.362		
Total	105	111447.0			
Tide	df	SS	MS	F-statistic	p-value
parameter	1	73381.7	73381.7	270.51	$6.80584*10^{-23}$
Residual	55	14919.9	271.271		
Total	56	88301.6			
Sea	df	SS	MS	F-statistic	p-value
parameter	1	106511.0	106511.0	453.702	$8.44155*10^{-32}$
Residual	68	15963.6	234.759		
Total	69	122474.0			

Based on the SS regression, the total variation in the percentage of oxygen can be determined in accordance with regression model i.e., the value of R^2. The linear model describing the influence of the air also explains the variability of 78.6% in the empirical data on the percentage increase in oxygen. This percentage equals 83.1% and 87% under the influence of tides and seas, respectively. Lower values were desirable for the SS residual. Namely, low values of the SS residual mean that the model well describes the variability in empirical data. In that sense, it can be concluded that the model best describes the behavior of the percentage change in oxygen under the influence of tides.

Very low p-values were obtained for the three types of the marine environment analyzed, and for the three linear models. The low p-values indicate an evident correlation between the increase in the percentage of oxygen and the increase in the duration of exposure of the sample to the influence of the environment observed.

The numerical data related to the estimated model parameter are presented in Table 4. Standard error represents the deviation of the coefficient of the linear term in the observed model in different cases. The value of t-statistics equals the quotient of the coefficient estimate and standard error.

Table 4 Parameter table

Coefficient	Estimate	Standard Error	t-statistics	p-value	Confidence interval
Air	2.51067	0.128474	19.5422	$1.34551*10^{-36}$	[2.2559, 2.76544]
Tide	3.38402	0.20575	16.4472	$6.80584*10^{-23}$	[2.97168, 3.79635]
Sea	3.99907	0.187747	21.3003	$8.44155*10^{-32}$	[3.62443, 4.37372]

The fact that all values of t-statistics are high, while the associated p-values are far below 0.05, is another proof of a high probability that the coefficients of the linear terms are different from zero i.e., that there is a significant correlation between dependent and independent variables. The last column of Table 4 shows the corresponding confidence interval (95%) for each of the calculated coefficients of the linear models (8) - (10). These intervals show the range in which the unknown coefficient is most likely found.

5. CONCLUSION

Based on the existing linear models of corrosion rate, this paper examined, with a high degree of acceptability, the linear model of the increase in oxygen content in the Cu-Al-Ni alloys which were exposed to various influences of the marine environment for 6 and 12 months. Statistical analysis showed a correlation between the percentage of oxygen and the time of exposure of the sample to the marine environment. Namely, the percentage of oxygen increases along with the increase in the duration of exposure to the air, tides, and sea. The greatest increase was observed under the influence of the sea, slightly lower under the influence of the tide, while the lowest percentage increase in oxygen occurred under the influence of the air. The confidence intervals determined in the statistical analysis indicate that with the certainty of 95% it can be stated that the average monthly increase in the percentage of oxygen is between 2.2559 and 2.76544 under the influence of the air, between 2.97168 and 3.79635 under the influence of tides, and under the influence of the sea the increase varies between 3.62443 and 4.37372.

Acknowledgment:

This paper is a result of the research on the different influences of seawater on the production and application of smart materials of shape memory alloys in maritime industry. Project PROCHA-SMA is a part of the EUREKA Project which is jointly realized by the Faculty of Stomatology in Belgrade, Zlatarna Celje, and the Faculty of Maritime Studies Kotor, University of Montenegro.

REFERENCES

[1] Rottiers, W., L. VandenBroeck, C. Peeters and P. Arras, "Shape memory materials and their application," pp. 3-5, 2011.

[2] G. Kauffman and I. M. Educator, “The story of nitinol: the serendipitous discovery of the memory metal and its applications,” *Chem. Educ. Springer*, 1997., no. 2, pp. 1–21.

[3] Tatjana Volkov-Husovic , Ivana Ivanic, Stjepan Kožuh, Sanja Stevanovic, Milica Vlahovic, Sanja Martinovic, Srecko Stopic, Mirko Gojic, “Microstructural and Cavitation Erosion Behavior of the CuAlNi Shape Memory Alloy”, Metals 2021, 11, 997. https://doi.org/10.3390/met11070997

[4] Jose San Juan, Applications of Shape Memory Alloys to the Transport Industry, International Congress on Innovative Solutions for the Advancement of the Transport Industry, At San Sebastian, Spain, October 2006

[5] J. Mohd Jani, M. Leary, A. Subic, and M. A. Gibson, “A review of shape memory alloy research, applications and opportunities,” Mater. Des., 2014, vol. 56, pp. 1078–1113, doi: 10.1016/j.matdes.2013.11.084.

[6] Š. Ivošević and R. Rudolf, “Materials with Shape Momory Effect for Application in Maritime,” Sci. J. Polish Nav. Acad., 2019, vol. 2018, no. 3, pp. 25–41, doi: 10.2478/sjpna-2019-0016.

[7] Š. Ivošević, R. Rudolf, and D. Kovač, “The overview of the varied influences of the seawater and atmosphere to corrosive processes,” in 1st International Conference of Maritime Science & Technology, NAŠE MORE, 2019, pp. 182–193.

[8] Guoa, Jinting, Wang, Ge, Ivanov, Lyuben, Perakis, Anastassios N.: "Time-varying ultimate strength of aging tanker deck plate considering corrosion effect", Journal of Marine Structures, Vol. 21 No. 4, October, 2008, pp. 402-419

[9] J. Paik, S. Kim, and S. Lee, “Probabilistic corrosion rate estimation model for longitudinal strength members of bulk carriers,” Ocean Eng., 1998, vol. 25, no. 10, pp. 837–860, doi: https://doi.org/10.1016/S0029-8018(97)10009-9.

[10] S. Qin and W. Cui, “Effect of corrosion models on the time-dependent reliability of steel plated elements,” Marine Structure, 2003. , vol. 16, pp. 15-34.

[11] C. Soares, Y. G.-J. of ship Research, and U. 1996, “Reliability of maintained ship hulls subjected to corrosion,” J. Sh. Res., 1996, vol. 40, no. 03, doi: https://doi.org/10.5957/jsr.1996.40.3.235.

[12] Š. Ivošević, R. Meštrović, and N. Kovač, “An Approach to the Probabilistic Corrosion Rate Estimation for Inner Bottom Plates of Bulk Carriers,” Brodogradnja, 2017, vol. 68, no. 4, p. 57/70, doi: 10.21278/brod68404.

[13] Š. Ivošević, R. Meštrović, N. Kovač, “Probabilistic estimates of corrosion rate of fuel tank structures of aging bulk carriers,” Int. J. Nav. Archit. Ocean Eng., 2019, vol. 11, no. 1, pp. 165–177, doi: https://doi.org/10.1016/j.ijnaoe.2018.03.003.

[14] Š. Ivošević, G. Vastag, P. Majerič, D. Kovač, and R. Rudolf, "Analysis of the Corrosion Resistance of Different Metal Materials Exposed to Varied Conditions of the Environment in the Bay of Kotor," in The Handbook of Enviromental Chemistry, Springer, 2020.
[15] Š. Ivošević, R. Meštrović, N. Kovač, "A Probabilistic Method for Estimating the Percentage of Corrosion Depth on the Inner Bottom Plates of Aging Bulk Carriers," J. Mar. Sci. Eng., 2020, vol. 8, no. 6, p. 442, doi: https://doi.org/10.3390/jmse8060442.
[16] „Coastal Sea Ecosystem Monitoring Program of Montenegro during 2019. and 2020., Institute of Marine Biology, University of Montenegro.
[17] R. Ivošević, Š., Majerić, P., Vukićević, M., Rudolf, "A Study of the Possible Use of Materials With Shape Memory Effect in Shipbuilding," J. Marit. Transp. Sci., 2020., vol. Spec. ed., no. 3, pp. 265–277.

THE INFLUENCE OF IMPORTANT MACROECONOMIC FACTORS ON TARIFF TRENDS AND THE SHIPOWNERS BUSINESS IN COASTAL LINER PASSENGER TRANSPORT IN THE REPUBLIC OF CROATIA

Alen Jugović
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: alen.jugovic@pfri.uniri.hr

Petra Adelajda Zaninović
University of Rijeka, Faculty of Economics
Rijeka, Croatia
E-mail: petra.adelajda.zaninovic@efri.hr

Dea Aksentijević
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: dea.aksentijevic@pfri.uniri.hr

UDK 656.025.2: 656.61(497.5)
330.101.541

Abstract

Coastal liner passenger shipping is of strategic importance to small open economies like Croatia that rely heavily on tourism. It provides transport links between islands and the mainland, enabling their economic development and reducing the out-migration of island populations. Macroeconomic trends have a strong impact on the business of shipping companies providing coastal liner passenger transport services. Therefore, the aim of this paper is to analyze the correlation between key macroeconomic indicators and tariff trends for passenger vehicles of up to 5 meters in length, as well as tariff trends for persons over 12 years in coastal liner passenger shipping. The analysis is based on secondary statistical data covering the period from 2010 to 2019 and including national RORO maritime passenger shipping lines. The results show that the tariff trends in coastal liner passenger shipping does not follow the trends of the main macroeconomic indicators. In fact, although the Republic of Croatia experienced growth in GDP rates, as well as consumer price inflation and growth in net wages and prices of oil and petroleum products, shipping business stagnated in relation to RORO liner passenger shipping in the Republic of Croatia. Tariffs did not change significantly - on the contrary, when calculating the tariff average for all lines, tariffs for vehicles up to 5 meters generally decreased, while tariffs for persons over 12 years fluctuated. The results of this analysis indicate that the shipowners of coastal RORO liner passenger shipping in the Republic of Croatia would operate more successfully if the tariffs followed the macroeconomic trends in the economy.

Keywords: macroeconomic trends, maritime passenger shipping, coastal liner passenger transport, tariffs, Republic of Croatia

1. INTRODUCTION

Transport, and in particular maritime transport, plays a key role in economic growth and development, as confirmed by a number of theoretical and empirical studies (Vlahinić Lenz et al. 2018). Fast and cheap transportation was one of the most important products of the Industrial Revolution, and it has indeed played an important role in changing the world from a multitude of closed economies to today's global economic system (Domian-Arneri 2014). Maritime shipping has contributed to the development of coastal countries. However, just as transport affects economic growth, the economy also affects transport from both macro and micro perspectives.

Maritime passenger shipping has developed primarily due to the constant need to transport passengers from point (port) A to point B, i.e., the destination. The development of maritime passenger shipping is of great importance for the Croatian economy, as it is highly dependent on tourism and thus also on island tourism. It also provides transport links between the islands and the mainland, thus enabling their economic development, which ultimately leads to a reduction or slowing down of the out-migration process of the island population. However, maritime passenger shipping is also influenced by national and global macroeconomic trends. Macroeconomic parameter trends such as gross domestic product (GDP), inflation, employment rates, salaries and fuel prices have a significant direct and/or indirect impact on the passenger shipping business.

In this paper, the authors analyse macroeconomic indicators affecting shipowner business in RORO passenger shipping and tariff formation in RORO liner passenger shipping. The aim of this paper is to analyse the relationship between the main macroeconomic indicators and tariff trends for passenger vehicles and persons in liner passenger shipping. The analysis is based on the tariffs of the shipping company Jadrolinija, which covers over 90% of the ferry lines in the Republic of Croatia.

This paper consists of five parts. After the introduction, the second part of the paper presents the theoretical framework and basic features of liner passenger shipping in the Republic of Croatia. The third part analyses the macroeconomic factors affecting the business of shipowners in the Republic of Croatia, while the fourth part analyses the correlation between the main macroeconomic indicators and tariffs in RORO liner passenger shipping. The fifth part of the paper discusses the results of the research and provides the main conclusions and recommendations resulting from the analysis.

2. BASIC CHARACTERISTICS OF LINER PASSENGER SHIPPING IN THE REPUBLIC OF CROATIA

RORO liner passenger shipping involves the transportation, transfer and conveyance of baggage, automobiles, and passengers from the port of origin to the port of destination according to a well-defined and published shipping timetable. This transportation may be direct or include stops at ports along the way. According to the shipping timetable, the transport is carried out by a group of ships with the same or similar characteristics that form a line (Rathman, Tijan and Jugović 2016).

According to Art. 4 of the Act on Transport in Liner and Occasional Coastal Maritime Transport (2019), the shipping timetable contains the following for each line:

- name of the shipowner,
- line number and type,
- port of call,
- mandatory time of departure and arrival at the port or the duration of the trip,
- the period during which transport is carried out on that line,
- term of validity of the shipping timetable.

The main regulatory authority of the Republic of Croatia for the matters of regular passenger transport in the Adriatic Sea is the Agency for Coastal Lines and Maritime Transport, which selects, through public tenders, a shipowner providing transport services on state ferry, ship and high-speed ship lines in public coastal maritime liner transport (Agency for Coastal Lines and Maritime Transport 2021). In 2020, in the Republic of Croatia, there were 24 state ferry lines (RORO lines), 11 ship and 15 high-speed ship lines with public service obligations and 2 lines without public service obligations.

Maritime passenger shipping is a topic of current interest in research papers, especially in countries where it is strongly linked to the economy and accounts for a significant share of the value added to the national economy. In order to ensure equal economic development conditions for islands and the mainland, coastal liner services are essential (Stupalo, Jolić and Jugović 2012). The national public system of coastal liner shipping is of strategic importance for Croatia, as it is, among other things, one of the prerequisites for the demographic development of the population (Rathman, Tijan and Jugović 2016). Modern passenger terminals are needed for the optimal functioning and development of maritime passenger liner transport and cruises. An appropriately sized and organized passenger terminal is also a prerequisite for the development of numerous complementary activities related to maritime passenger transport. First and foremost, it helps in improving the tourist offer and developing tourism (Jugović, Kesić, Jakomin 2007, p. 146). Besides tourism, maritime passenger transport is also very important when it comes to sustainability, especially the sustainable development of islands and their connections to the mainland. Liner maritime passenger transport is important for the development of the coastal economy, especially for tourism and trade, as well as for preventing the outflow of the population from the islands. Consequently, it is necessary to invest in the modernisation of liner passenger vessels so that they can withstand the difficult winter sailing conditions. In addition, an extension of the tourist season would lead to more frequent lines.

3. FACTORS AFFECTING ONE'S BUSINESS IN LINER PASSENGER SHIPPING

In this part of the paper, the macroeconomic factors influencing the shipping business in maritime passenger shipping are analysed. The following factors are analysed: Gross Domestic Product, inflation, wages and the price of oil and petroleum products.

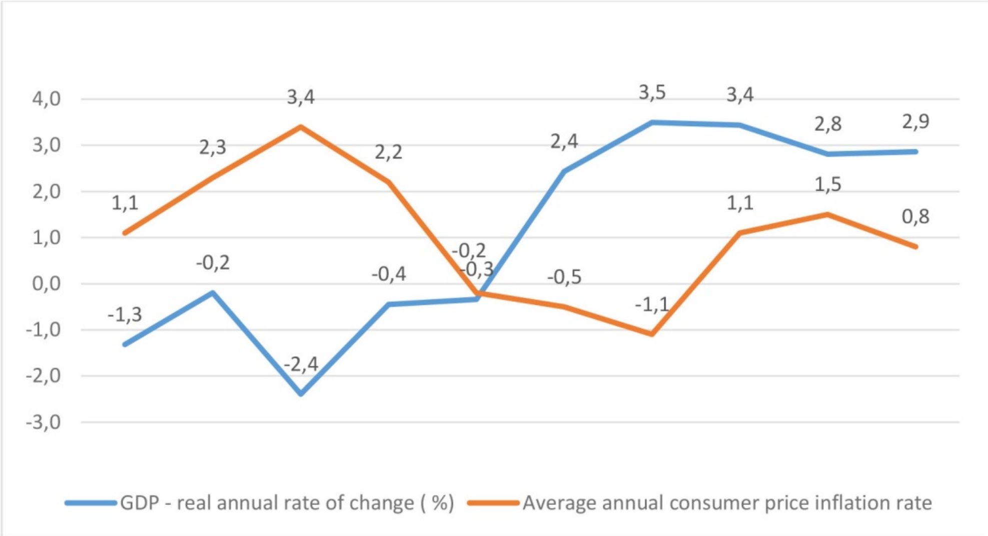
3.1. Gross Domestic Product trends for the 2010 – 2019 period

From the beginning of the financial crisis in 2008 until a slow recovery in 2015, there was a decline in GDP. After 2015, there was slight GDP growth, which then slowed in 2018 and 2019 (Graph 1). Although official data has not yet been released, a significant decline in the GDP rate was also observed in 2020 due to the epidemiological crisis caused by COVID -19. GDP indicates the state of the economy, and its trends have a significant impact on the business of shipowners. Particularly noteworthy are the periods when economic shocks have a significant negative impact on both GDP and shipowners' business.

In 2015, the economic recovery led to GDP growth, which was mainly influenced by revenues generated primarily from tourism, export of services and export of goods as a result of the Republic of Croatia's accession to European Union. There was no contribution of domestic demand to the growth of economic activities, but changes in tax policy, especially income tax (2015, 2017, 2018), led to the growth of personal consumption, which also influenced the growth of GDP. Growth in aggregate demand stimulated growth in the production of goods and services, with the largest contribution observed in manufacturing and trade, transport, storage and hotels and restaurants. No significant GDP growth was observed in the last two years observed (2018 and 2019). The slight slowdown in economic growth is primarily the result of an unfavourable global environment (trade war, slowdown in Eurozone and EU economic growth, Brexit). Moreover, it was unrealistic to expect tourism demand growth to continue at the pace observed in recent years.

3.2. Inflation trend for the period from 2010 to 2019

The inflation rate is calculated using consumer price index data and is shown as the change in the prices of goods and services for personal consumption between the base (initial) month and the last month of the selected period. Graph 1, which displays the average annual rate of consumer price inflation in the period 2010 - 2019 in percent, shows a significant increase in the inflation rate during the economic crisis and a decrease in this rate during the period of economic recovery of the Republic of Croatia. The sharpest decrease in the inflation rate was observed in 2016, after which a slight increase was observed again.



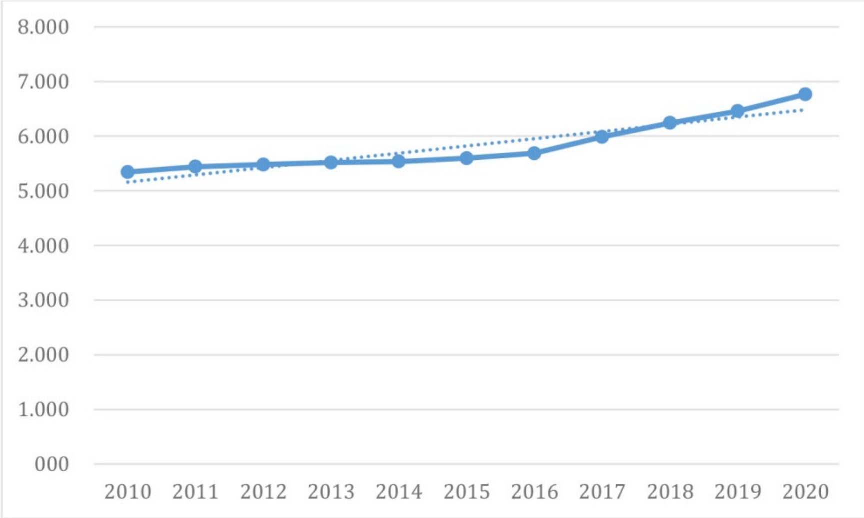
Graph 1 GDP real annual rate of change and average annual consumer price inflation rate, 2010 – 2019, in %

Source: Croatian National Bank 2021

Graph 1 shows the growth in the consumer price index in 2010. After the end of the economic crisis, the Republic of Croatia continued to be affected by its consequences until 2015, when a significant decrease in prices was observed. This decline was partly the result of a decline in raw material prices and energy prices (crude oil, coal and gas) on the world market in July 2015 (as can be seen in Graph 5). After 2016, an increase in consumer prices was observed again. Direct main drivers of a stronger increase in the general price level were the price development of crude oil and petroleum products. In 2018 - 2019, there was a decrease in consumer prices in the Republic of Croatia, which in turn was the result of a decrease in oil prices on the world market.

3.3. Salary trends for the 2010 – 2020 period

Average salary growth in the Republic of Croatia is becoming more pronounced (Graph 2). This is not only a consequence of increased productivity, but also a consequence of the decline in the labour force, i.e. migration. Wage setting and dynamics depend on demographic trends and the economic structure of individual regions, i.e. the availability of labour in certain sectors and the need to stem the flow of emigration.

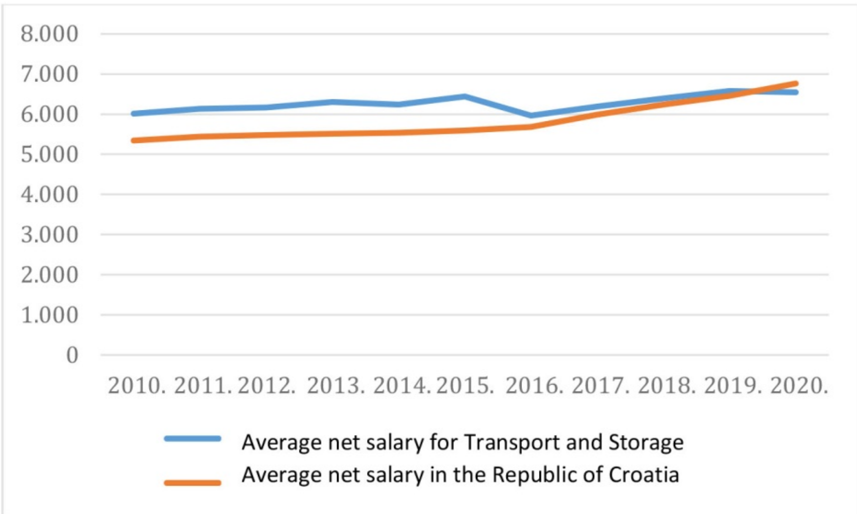


Graph 2 Average monthly net salary trends in the Republic of Croatia, 2010 – 2020

Source: Croatian National Bank 2021

In 2019, the average salary increased by 13 percentage points compared to 2016. In Croatia, there has been a continuity of salary growth at the national level in the observed period, which has greatly contributed to an increase in disposable resources and household purchasing power, allowing for growth in both retail and personal consumption, which, in our circumstances, is an important determinant of growth in overall economic activity, i.e. GDP. Salary growth accelerated especially in the last three years of the observed period, due to the influence of stabilization of economic growth and positive shifts in the labor market (e.g. labor supply-demand equilibrium), as well as tax changes aimed at increasing net wages and reducing the tax burden on labor. However, compared to other countries of similar economic size, the dynamics of salary growth is generally lower, which means that other countries are catching up with Croatia and are ahead of it in terms of salaries.

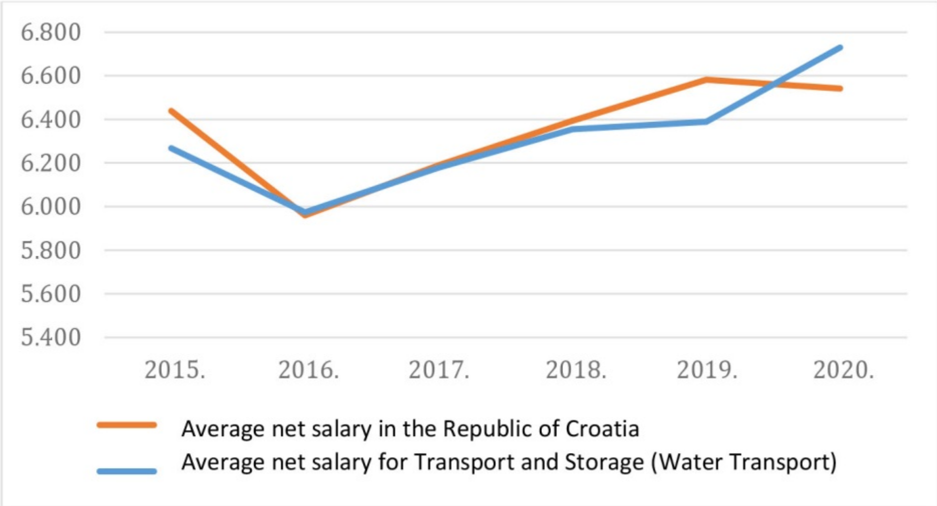
Graph 3 shows that the salaries of employees in the transport and storage sector are above the average salary in the Republic of Croatia until 2019. A smaller decrease can be seen in the period 2015 - 2016, and it is slightly higher compared to the decrease in the average net salary.



Graph 3 Average net salary trends in Transport and Storage sector, 2010 – 2020

Source: Croatian Bureau of Statistics 2021

In the period 2016 - 2018, an increasing trend can be observed in both average salaries in the transport and storage sector and in overall average salaries in the Republic of Croatia. Looking at the slope of the curves of both observed values, we can see that the average salary in the Republic of Croatia grew faster than the average salary in the transport and storage sector during this period, i.e. the increase in salaries in the transport and storage sector did not follow the increase in salaries at the level of all sectors. In 2018, average salaries in the transport and storage sector started to decrease, while average salaries in the Republic of Croatia continued to increase, with a slightly smaller difference observed in 2020.



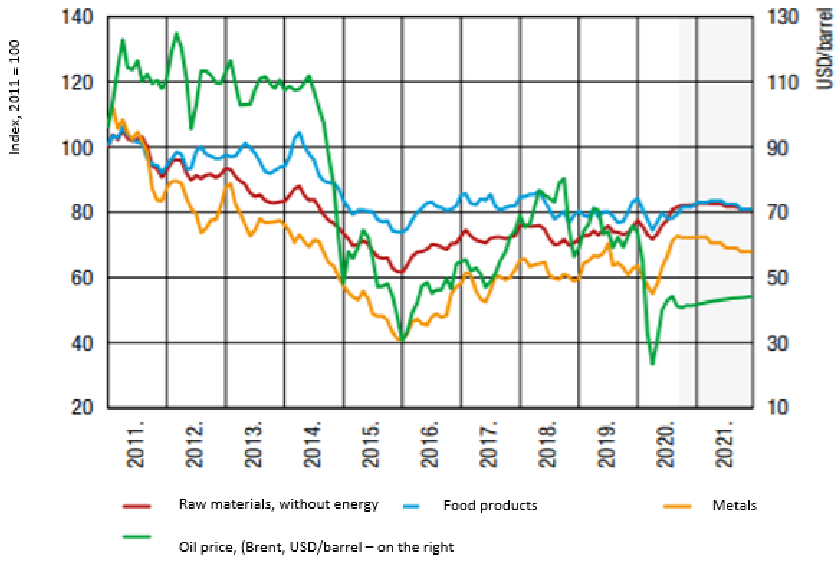
Graph 4 Average net salary trends in Water Transport sector, 2015 – 2020

Source: Croatian Bureau of Statistics, 2021

Since 2015, Croatian Bureau of Statistics has been publishing data on Water Transport salary trends. When comparing the trends of overall average salary and average salary in Water Transport, it was found that until 2018, they generally had a similar trend and were almost equal amounts. In 2018, there was a small increase in the average net salaries in the Republic of Croatia, while the Water Transport salaries did not change significantly. However, in 2019, there was an increase in the salaries of employees in Water Transport, which was a consequence of the increase in salaries in the transport and storage sector in general (Croatian Bureau of Statistics, 2021).

3.4. Price trends of oil and petroleum products for the 2011 – 2021 period

The development of the price level for oil and petroleum products has a significant influence on the development of the economy and thus also on the general price level (inflation) and the price development in the transport sector. Therefore, every increase and decrease in the prices of raw materials and energy (crude oil, coal and gas) on the world market affects the general price level and determines the percentage of inflation and deflation.



Graph 5 Price of raw materials on the international market, 2011 – 2021 (projections)

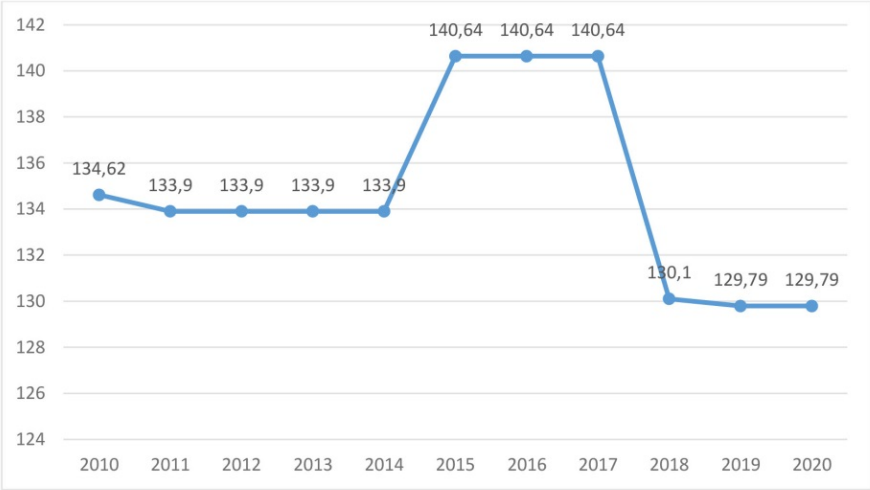
Source: Croatian National Bank, 2021

Graph 5 shows the fluctuating trend of raw material prices in the international market. Although the fluctuation of the dollar exchange rate usually determines the trend of commodity prices, i.e. oil prices, an oil crisis occurred in 2020 due to the external shock related to the pandemic caused by COVID -19, which caused a negative oil price level. It is expected that the recovery of world trade in 2021 will bring oil prices back to a higher level and even lead to a price increase, which will affect the cost of oil-dependent activities, such as the transport and maritime sectors. If we compare the development of crude oil prices on the world market and the sales prices of Eurodisel in Croatia, it becomes clear that although prices in the Republic of Croatia follow the development of crude oil prices on the world market, they are also still significantly higher.

In the event of a change in the ship's bunker fuel price on the market, the Agency for Coastal Lines and Maritime Transport covers the difference between the contracted and actual cost of ship's bunker fuel price. Nevertheless, the price of oil and petroleum products has a great impact on inflation, and therefore it is important to analyse it in more detail.

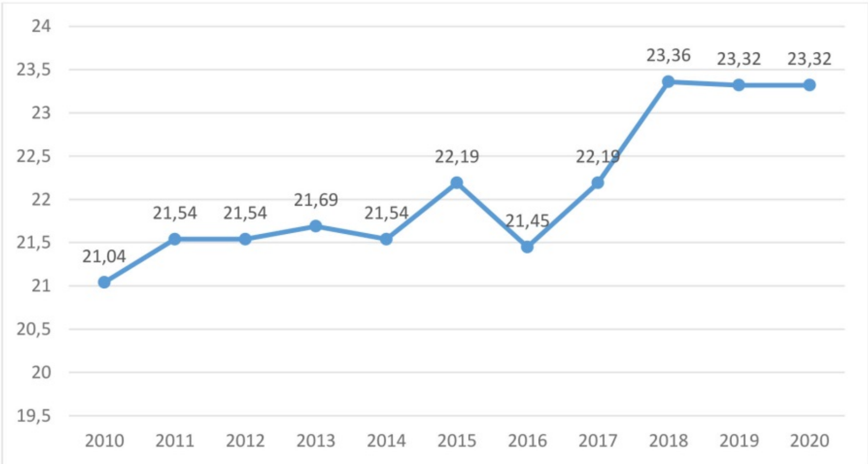
4. RELATIONSHIP BETWEEN THE MACROECONOMIC FACTORS AFFECTING THE SHIPOWNER BUSINESS IN COASTAL LINER TRANSPORT AND THE PRICE OF MARITIME TRANSPORT SERVICES

In this part, the relationship between the macroeconomic factors affecting the shipowner business in coastal liner passenger transport and the tariffs for passenger vehicles and passengers in the liner passenger shipping industry is analysed. The analysis is based on the tariffs of the shipping company Jadrolinija, which covers over 90% of the ferry lines in the Republic of Croatia. Secondary statistical data is used for the analysis, which refers to the main macroeconomic indicators and average tariffs for passenger vehicles up to 5 meters in length and passengers over 12 years of age for all lines operating in the Republic of Croatia. The average tariffs are calculated based of the tariffs of 79 shipping line (Appendix 1.). The following Graph 6 presents the trend in average tariffs for passenger vehicles and Graph 7 average tariffs for passengers across all shipping (79) lines in the period from 2010 to 2020 expressed in Croatian kuna.



Graph 6 Average tariffs for passenger vehicles, 2010 - 2020

Source: Jadrolinija, 2021



Graph 7 Average tariffs for passengers, 2010 – 2020

Source: Jadrolinija, 2021

In order to analyse the correlation between the trends of macroeconomic indicators and tariffs, all variables were converted into growth rates and they all cover the period 2010 - 2020. Table 1 below shows the descriptive statistics of all variables used.

Table 1 Descriptive statistics

Variable	No.	Average	Standard deviation	Minimum	Maximum
(1) Vehicleprice_growth	9	-.3593137	3.175743	-7.494307	5.033611
(2) Personprice_growth	9	1.179482	2.599256	-3.334834	5.272645
(3) Brentprice_growth	9	15.77135	35.57313	-24.12588	89.17457
(4) Netwage_growth	9	2.67915	2.306882	.3390911	6.973171
(5) GDPgrowth	9	1.3	2.140678	-2.4	3.5
(6) Inflation	9	1.055556	1.468938	-1.1	3.4

Source: Authors' calculation

Table 2 shows a correlation matrix for the variables used in the analysis. The table shows that the correlation between the variables Vehicleprice_growth (1) and the Netwage_growth (4), GDPgrowth (5) and Inflation (6) is negative, i.e. the trend is negative. While the main macroeconomic variables showed growth rates, passenger liner vehicle tariffs generally stagnated or decreased for all lines. The correlation between the variables Personprice_growth (2) and Brentprice_growth (3) and Netwage_growth (4) is also negative. The only positive but small correlation is between passenger tariffs growth rates, GDPgrowth (5) and Inflation (6).

Table 2 Correlation matrix

Variable	(1)	(2)	(3)	(4)	(5)	(6)
(1) Vehicleprice_growth	1,000					
(2) Personprice_growth	-0,329	1,000				
(3) Brentprice_growth	0,063	-0,180	1,000			
(4) Netwage_growth	-0,236	-0,241	-0,409	1,000		
(5) GDPgrowth	-0,097	0,162	-0,228	0,793	1,000	
(6) Inflation	-0,315	0,316	-0,224	-0,442	-0,659	1,000

Source: Authors' calculation

4.1. Comparison of GDP growth rates and tariff growth rates in RORO liner passenger shipping

Graph 8 shows the comparison of trends in terms of the real annual rate of change in GDP and the annual rate in terms of the evolution trend in vehicle tariff (left), as well as trends in terms of passenger tariffs (right) in coastal liner passenger shipping. Looking only at GDP trends (marked with a dashed line on the left and right side of Graph 8), it is evident that there was a decline in its rates from the onset of the financial crisis in 2008 until the slow recovery in 2015. After 2015, there was a slight growth in GDP, but it slowed down again in 2018 and 2019. Analysis of vehicle tariff rates shows that they did not follow the macroeconomic trend. Instead, there was an increase in vehicle tariffs in 2015, but then they fell in 2018 and have remained almost the same since then. The personal Persons tariff rates also show an oscillating trend that does not follow the trend of GDP. There was a decline in the rate in 2016 and then a slow recovery in 2018. At the end of the observation period, there is again a decline in the rate growth. GDP shows the state of the economy, and its trends should have a significant impact on the shipping business. However, the data analysed shows the opposite - it indicates that there is some mismatch between economic growth and the average rate of tariff growth on all observed lines.

Graph 8 Comparison of the real annual rate of changes in GDP and the tariffs in RORO liner passenger shipping (%) 2010 – 2019

Source: Made by the authors based on the data by CNB and the Jadrolinija 2021

5. DISCUSSION AND CONCLUSION

This paper deals with the relationship between the macroeconomic factors affecting the shipowner business in coastal liner passenger transport and the tariffs for passenger vehicles and persons in liner passenger shipping. The main focus of the paper is on the shipping business in coastal liner passenger transport given its strategic importance for the Republic of Croatia, both in terms of tourism and transport accessibility and sustainable development of the islands. During the observed period, there was growth in the main macroeconomic factors, while vehicle tariffs in liner passenger shipping generally stagnated or decreased for all lines. The correlation between growth rates in passenger transport tariffs and growth rates in fuel prices and salaries is also negative. The only positive but small correlation is seen between the growth rates of passenger transport tariffs, the growth rate of GDP and the inflation rate of consumer prices.

In 2008, the economic crisis began for the Republic of Croatia, which lasted until 2015. After the crisis, there was a slight growth of GDP. The growth of GDP was mainly influenced by the revenues generated by tourism, export of services and export of goods as a result of the accession of the Republic of Croatia to European Union. Growth in aggregate demand stimulated growth in the production of goods and services. The highest growth was observed in the manufacturing industry, as well as in the trade, transport, storage and hospitality sectors. The analysis shows that GDP per capita growth was observed in the Republic of Croatia during the period 2015 - 2019. However, this was partly caused by a decrease in population due to migration to other EU Member States. The analysis of vehicle tariffs shows that they did not follow the macroeconomic trend. Instead, there was an increase in vehicle tariffs in 2015, but then they decreased in 2018 and have remained almost the same since then. By comparing GDP growth rates and tariff growth rates in coastal liner passenger shipping industry, it was found that there is an oscillating trend in tariff rates and that they do not follow GDP rate trends. The results of the analysis show a general mismatch between economic growth and average fare growth rates for all lines.

There was also salary growth in the Republic of Croatia. In 2019, salaries increased by 13 percentage points compared to 2016, which contributed to higher household purchasing power and demand for goods and services. In 2019, there was an increase in salaries of employees of Water Transport, which was a consequence of the increase in salaries in maritime passenger transport. In the last two years of the period under review (2018 and 2019), consumer prices increased by an average of 1.15%. The main direct drivers of a stronger increase in the general price level are the price developments of oil (petroleum products), which affect price developments in the transport industry. Oil prices are expected to increase, which will affect the cost of oil-dependent activities, such as the transportation and maritime sectors. All the above factors have a strong impact on the business of shipowners. Therefore, it is important to use economic policies to enable smooth operation of coastline transport at the national level to promote balanced economic development of coastal areas and islands.

REFERENCES

[1] Agency for Coastal Lines and Maritime Transport (2021) https://agencija-zolpp.hr/ , Accessed on: 27/03/2021

[2] Autonet (2020) https://www.autonet.hr/aktualno/cijena-goriva-prati-trziste-sirove-nafte-ali-trosarine-nas-ubijaju/_, Accessed on: 10/02/2021

[3] Croatian Bureau of Statistics (2021) https://www.dzs.hr/ , Accessed on: 20/02/2021

[4] Domijan-Arneri I. (2014) 'Poslovanje u morskom brodarstvu', Redak, Split, 2014., p. 7

[5] Euribor Rates (2021) euribor-rates.eu , Accessed on: 20/02/2021

[6] CNB – Croatian National Bank (2021) https://www.hnb.hr/statistika/glavni-makroekonomski-indikatori , Accessed on: 15/02/2021

[7] Jadrolinija (2121) https://www.jadrolinija.hr/redovi-plovidbe-i-cijene/lokalne-linije-2021- , Accessed on: 15/02/2021

[8] Jugović, A. Kesić, B. Jakomin, I. (2007) 'Organizacija i razvoj pomorsko-putničkih luka', *Informatologia*, 40 (2), pp. 146-152.

[9] Rathman, D., Tijan, E. and Jugović, A. (2016) 'Improving the coastal line passenger traffic management system by applying information technologies', *Multidisciplinary Scientific Journal of Maritime Research*, 30, pp. 12-18.

[10] Stupalo, V., Jolić, N. and Jugović (2012) 'Opportunities of passenger liner shipping development in Croatia', *7th International scientific conference on Ports and Waterways-POWA 2012 - Water transport within regional development context*, University of Zagreb, Faculty of Transport and Traffic Sciences, pp. 1-7.

[11] Vlahinić Lenz, N., Pavlić Skender, H, Mirković, PA (2018) 'The macroeconomic effects of transport infrastructure on economic growth: the case of Central and Eastern E.U. member states', *Economic Research – Ekonomska Istraživanja*, 31(1), pp. 1953 1964, DOI: 10.1080/1331677X.2018.1523740

[12] Act on Transport in Liner and Occasional Coastal Maritime Transport (2019) Available at: https://www.zakon.hr/z/441/Zakon-o-prijevozu-u-linijskom-i-povremenom-obalnom-pomorskom-prometu , Accessed on: 27/03/2021

APPENDIX

District	Lines	Destination
District of Rijeka	National ferry line 332	Valbiska - Merag and opposite
	National ferry line 334	Brestova - Porozina and opposite
	National ferry line 335	Prizna - Žigljen and opposite
	National ferry line 338	Valbiska - Lopar and opposite
District of Zadar	National ferry line 401	Zadar - Premuda and opposite
	National ferry line 401	Zadar - Silba and opposite
	National ferry line 401	Zadar - Olib and opposite
	National ferry line 401	Zadar - Ist i obratno
	National ferry line 401	Mali Lošinj - Premuda and opposite
	National ferry line 401	Mali Lošinj - Silba and opposite
	National ferry line 401	Mali Lošinj - Olib and opposite
	National ferry line 401	Mali Lošinj - Ist and opposite
	National ferry line 401	Zadar - Mali Lošinj and opposite
	National ferry line 401	Premuda - Olib and opposite
	National ferry line 401	Premuda - Silba and opposite
	National ferry line 401	Premuda - Ist and opposite
	National ferry line 401	Silba - Olib and opposite
	National ferry line 401	Silba - Ist and opposite
	National ferry line 401	Olib - Ist and opposite
	National ferry line 431	Zadar - Preko and opposite
	National ferry line 431	Zadar - Ošljak and opposite
	National ferry line 431	Preko - Ošljak and opposite
	National ferry line 432	Tkon (Pašman) - Biograd and opposite
	National ferry line 433	Zadar - Ist i obratno
	National ferry line 433	Zadar - Zapuntel i obratno
	National ferry line 433	Zadar - Molat and opposite
	National ferry line 433	Zadar - Zverinac and opposite
	National ferry line 433	Zadar - Sestrunj and opposite
	National ferry line 433	Zadar - Rivanj and opposite
	National line433	Rivanj - Ist and opposite
	National line433	Rivanj - Zapuntel and opposite
	National line433	Sestrunj - Ist and opposite
	National line433	Sestrunj - Zapuntel and opposite
	National line433	Rivanj - Molat and opposite
	National line433	Sestrunj - Molat and opposite
	National line433	Zverinac - Zapuntel and opposite
	National line433	Zverinac - Ist and opposite
	National line433	Rivanj - Zverinac and opposite
	National line433	Sestrunj - Zverinac and opposite
	National line433	Zverinac - Molat and opposite
	National line433	Molat - Zapuntel and opposite
	National line433	Molat - Ist and opposite
	National line433	Zapuntel - Ist and opposite

	National line433	Rivanj - Sestrunj and opposite
	National line434	Brbinj - Gaženica and opposite
	National line435	Zadar - Bršanj and opposite
	National line435	Zadar - Rava and opposite
	National line435	Zadar - Mala Rava and opposite
	National line435	Bršanj - Rava and opposite
	National line435	Bršanj - Mala Rava and opposite
District of Šibenik	National line532	Šibenik - Zlarin and opposite
	National line532	Zlarin - Kaprije and opposite
	National line532	Zlarin - Žirje and opposite
	National line532	Kaprije - Žirje and opposite
	National line532	Šibenik - Kaprije and opposite
	National line532	Šibenik - Žirje and opposite
District of Split	National line602	Vis - Split and opposite
	National line631	Supetar (Brač) - Split and opposite
	National line635	Stari Grad (Hvar) - Split and opposite
	National line632	Sućuraj (Hvar) - Drvenik and opposite
	National line633	Ploče - Trpanj (Pelješac) and opposite
	National line636	Rogač (Šolta) - Split and opposite
	National line638	Sumartin (Brač) - Makarska and opposite
	National line634	Dominče (Korčula) - Orebić (Pelješac) and opposite
	National line604	Split - Vela Luka and opposite
	National line604	Split - Lastovo and opposite
	National line604	Vela Luka - Lastovo and opposite
	National line604	Lastovo - Hvar and opposite
	National line604	Vela Luka - Hvar and opposite
	National line604	Hvar - Split and opposite
	National line606	Trogir - Drvenik Veli and opposite
	National line606	Trogir - Drvenik Mali and opposite
	National line606	Drvenik Veli - Drvenik Mali and opposite
	National line606	Split - Drvenik Veli and opposite
	National line606	Split - Drvenik Mali and opposite
District of Dubrovnik	National line831	Dubrovnik - Suđurađ and opposite
	National line831	Dubrovnik - Lopud and opposite
	National line831	Lopud - Suđurađ and opposite
	National line832	Sobra - Prapratno and opposite

Source: Jadrolinija, 2021

COMPARATIVE ANALYSIS OF TARIFF MODELS IN RO-RO TRANSPORT IN CROATIA, ITALY AND GREECE

Alen Jugović
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: ajugovic@pfri.hr

Valentina Šutalo
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: sutalo@pfri.hr

Dea Aksentijević
University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: dea@pfri.hr

UDK 656.614.2:656.66
656.031(450)(495)(497.5)

Summary

Coastal liner passenger transport in the Republic of Croatia is the main means of connecting the islands with the mainland and the islands with each other, ensuring the basic living conditions of the inhabitants, promoting their mobility, reducing social and economic inequalities and increasing the sustainability of the islands. Due to their complexity, their extremely seasonal nature and their economic activity of public interest, maritime connections are regulated by numerous legal acts, but the way in which tariffs are set has not yet been systematically defined. In Greece and Italy, ticket prices and categories of passengers and vehicles are related to the pricing policy of the ferry operator, while in Croatia the national government is involved in the formation of ticket prices and privileged groups. The aim of this article is to analyze the categories and the way of setting tariffs for passengers and vehicles in ferry coastal passenger transport in Croatia and to compare them with those in Greece and Italy. The analysis was carried out on the example of the Jadrolinija shipping company, which is the dominant ferry operator in Croatia. The research shows that Italian and Greek operators have a larger number of categories for passengers and vehicles and have a different way of setting tariffs for these groups than in Croatia. Based on a comparative analysis of the tariff models applied in Italy and Greece, this paper proposes a modification of the existing tariffs applied in the coastal liner passenger transport of Croatia.

Keywords: tariff models, RO-RO transport, organization, Mediterranean, passengers

1. INTRODUCTION

Coastal line passenger transport is of extraordinary importance for the economy of the Republic of Croatia. It is a method of transporting passengers and goods according to a predetermined and published timetable between the port of departure and the port of destination. In addition, coastline transport in the Republic of Croatia remains the essential means of connecting the mainland and the islands. All services are publicly available to potential users of this form of transport and to potential business partners. Public maritime transport is provided by carriers that have concluded a public service contract for a specific line, i.e. for a group of lines, if there are economic, demographic or other important reasons for doing so [1], [2].

In line with the Law on public transport in liner shipping and occasional coastal maritime traffic in the Republic of Croatia, a public transport system should be established to ensure regular connection of the inhabited islands with the mainland and the inhabited islands with a sufficient number of daily connections in both directions, in order to create better living conditions on the islands and promote their sustainable development[3]. For this reason, more investment is needed in the modernization of more suitable liner passenger vessels for carrying out the service in difficult winter sailing conditions [4]. In addition, the extension of the tourist season would lead to a higher demand for coastal liner services and an increase in profitability on certain lines [5].

The establishment of a public transport system is based on the principles:[3]

- promotion of the economic development of the island,
- continuity and regularity of service with vessels of a certain capacity and type, and ensuring adequate quality of service,
- transport services with fixed prices and other conditions
- support for shipowners, without which the continuity and regularity of public transport on certain routes cannot be guaranteed
- adapting public transport to actual needs,
- provision of additional transport services.

The general provisions of the Law on public transport in liner shipping and occasional coastal maritime traffic in the Republic of Croatia regulate the conditions and manner of providing public transport services of general economic interest. In accordance with the Law the types of lines are defined, as well as the establishment and harmonization of timetables, price lists of services, provision of funds for continuous and regular public transport. In the same Act, liner public transport is determined as the transport of passengers, goods and vehicles in the internal maritime waters and the territorial sea of the Republic of Croatia, carried out on predetermined routes in conformity with publicly announced timetables and price lists.

Based on the importance of the route, the lines on which public transport is carried out are divided into: national, local and international lines. According to the type of transport they are divided into: Ferries (RO - RO), high-speed and classic ship lines [3]. In order to analyze the way of tariff setting, only data related to national ferry lines will be considered in the following chapters. In Croatia, RO -RO are passenger ships that allow people to drive their own vehicles the whole trip along the coast. This is evident in the synergy and link with road transport, which is without a doubt one of the most essential modes of transportation. The analysis is predominantly based on the most recent present data wherever possible and appropriate. Where new data were not available, the most recent sources available were used. For those analyzes where it was necessary to aggregate data, the aggregation of data was done through consultation with several experts or institutions in the field. For example, institutions in Greece and Italy were also contacted for the purpose of comparing tariffs.

In this paper, authors will analyze in detail the tariffs and possibilities of tariff design for RO - RO lines with a particular focus on Greece and Italy. The aim is to emphasize the possible need for correction of the tariff model applied in the Republic of Croatia, as well as other anomalies resulting from the above analysis. A proposal has been brought forward to modify the tariff model in the coastal liner passenger transport in the Republic of Croatia for the RO - RO lines. It should be emphasized that a possible proposal to increase fares will not apply to island residents, more precisely to persons with an island card, but only to tourists and their means of transport, as well as to other visitors to the islands.

This paper consists of five parts. After the introduction, the second part of the paper presents the role of tariffs in costal liner passenger transport. The third part analyses tariffs and methods of defining tariffs for ferry lines in costal liner passenger transport in the Republic of Croatia. In fourth part of the paper Croatian sea passenger transport is compared with other European countries and analyses tariffs in Italy and Greece, leading countries in terms of maritime passenger transport in the EU. Fifth part discusses the results of the research and provides the main conclusions and recommendations resulting from the analysis.

2. THE ROLE OF TARIFFS IN COASTAL LINER PASSENGER TRANSPORT

The term tariff, in the narrowest sense of the word, means price, that is, a systematic review of certain pecuniary benefits. Tariffs include specific legal rules, criteria and circumstances for operationalizing transport services, which, in addition to pricing the transport service, relate to specific transport behaviors reflected in the value [6].

According to Zelenika, tariffs serve to inform interested parties about prices in maritime transport [7]. Tariffs, when published, help customers to calculate the cost of travel in advance, but they usually do not affect the volume of demand. Tariffs are suitable for recurring shipments, certain lines, selected commodities, and certain types of transportation. The advantage of the tariff is its simplicity, since the customer can estimate the cost of transportation based on a specific method [8]..In liner shipping, the carrier sets the line tariff for each line separately and very often for each direction of travel, which depends on the structure of the cargo received for transportation on each line or direction of travel [9].

When forming the tariff, it is important to consider all the parameters that are crucial for its formation. These include the following parameters: Transport price, transport conditions and prices for additional services (e.g. weighing, loading and unloading, transshipment, storage of goods, empty runs...). Tariffs differ according to the object of transport, therefore, they are divided into passenger tariffs and freight tariffs, both of which have their own subcategories. The tariff, as a published list of prices and conditions for maritime transport, is a means by which all interested parties can inform themselves about the services offered by a shipping company. This applies to liner passenger shipping and liner cargo shipping, and to some extent to tanker shipping, while the contract for free shipping rates and conditions is a matter of agreement between the carrier and the customer [7].

3. ANALYSIS OF TARIFFS AND METHODS OF DEFINING TARIFFS FOR FERRY LINES IN COASTAL LINER PASSENGER TRANSPORT IN THE REPUBLIC OF CROATIA

For the Republic of Croatia, which has a highly indented coastline and many inhabited islands, passenger transport is of significant importance, as it is maintained with the aim of achieving a higher standard of living for the local population, better island accessibility and greater sustainability of the islands. Passenger transport is provided on fixed routes, on which the price, offer, travel conditions and discounts are indicated, and passengers cannot plead ignorance of travel conditions or prices, as they can access them at any time. Considering that the Republic of Croatia is a tourist country, it is possible during the summer months, due to an increased demand for transport, additional vessel capacity will be hired according to the current demand, in addition to the regular lines.

3.1. Division of maritime passenger lines

Maritime passenger lines on which public transport is operated may be classified according to the importance of the direction:[10]

1. national lines - lines connecting the coast with inhabited islands and islands with each other, and coast lines
2. county and intercounty lines - lines improving the maritime connection of inhabited islands and settlements on the mainland, islands with each other, or the connection of settlements on the mainland in the area of one or more counties
3. local lines - lines improving the maritime connection of islands and settlements on the mainland, islands with each other, or the connection of settlements on the mainland in the area of the municipality or city.

According to the type of transport, lines are divided into:[3]

1. ferry lines (RO - RO lines) - traffic on this type of lines is carried out by vessels specially built for transporting vehicles and passengers
2. high-speed lines - are carried out with fast passenger ships defined in Article 5 of the Maritime Navigation Law (OG 181/04)
3. classic shipping lines - are operated by passenger ships whose speed is not less than 12 knots.

For the purposes of writing this paper and carrying out a more detailed analysis, only the national lines will be considered, if the division by type of transport is observed, only the RO - RO lines will be analyzed in terms of their specific seasonal character, the specific way of tariff formation and the differences in tariff formation compared to other European countries.

3.2. Analysis of the tariffs for the transport of passenger in Republic of Croatia

The analyzed lines are most often operated by ferries - these are combined ships that can accept a certain number of personal vehicles, trucks or buses in addition to passengers. The tariff is defined for vehicles according to height, length, passenger capacity and load capacity, therefore the company Jadrolinija distinguishes in its tariffs 8 main categories of vehicles that may or may not be followed by their driver. These categories are later divided into subcategories depending on the characteristics of the vehicle as shown in Table 1.

Table 1 Vehicle categories depending on the type and characteristics of the vehicle

TYPE OF VEHICLE	CHARACTERISTICS
Passenger car (up to 9 seats)	up to 5.00 m long and / or 2.00 high
	over 5.00 m in length and / or above 2.00 m in height
Lightweight (luggage trailer)	up to 3.00 m
	From 3.01 to 5.00m in length
	over 5.01 m length
Trailer (caravan, trailer, ...) camper	vehicle up to 5.00 m long
	from 5.01 to 7.00 m in length
	over 7.00 m long
Bus	from 10 to 17 seats
	from 18 to 33 seats
	from 34 to 54 seats
	over 54 seats
Truck	p to 3.00 t load capacity
	from 3.01 t to 4.00 t load capacity
	from 4.01 t to 5.00 t load capacity
	over 5.01 t load capacity
Motorcycle, moped	-
Motorcycle with trailer, tricycle, quad bike -	-
A bike	-

Children up to the age of 3 are generally entitled to free travel on all lines without restrictions such as number of journeys. Children up to the age of 12 are entitled to a discount on the basic fare, adults generally pay the full fare, but hand luggage is not charged. The following are also entitled to free transport: bus drivers, bus passengers, lorry drivers up to 10 tons, accompanying lorry drivers over 10 tons, pupils and students living on the island and studying on the mainland, pensioners over 65 years of age and elderly people (+65 years) living on the island.

3.3. Conditions and possibilities of realizing the right to preferential transport on public maritime transport line

In accordance with Ordinance on the conditions and manner of realization of the right to privileged transport on public maritime transport lines (Ordinance) the conditions and manner of realizing the right to privileged transport: the amount of the discount for the use of the right to privileged transport and the types of documents issued to users of the right to privileged transport [11].

Users residing on the island have the right to privileged transport on ferries, classic and high-speed lines in public transport with a public service obligation, connecting the island of their residence with the mainland or another island, by granting a discount on the current fare. In accordance Article 4 of the Ordinance on the conditions and manner of realization of the right to privileged transport on public maritime transport lines users are entitled to a reduced fare ticket for one return journey.

Table 2 Islands and lines / routes whose users have the exclusive right to privileged transportation [11]

ISLAND	LINE MANE	ROUTE
BIŠEVO	T602	Vis – Split
CRES	T401	Mali Lošinj – Zadar
ILOVIK	T332	Valbiska – Merag
	T334	Brestova – Porozina
	T401	Mali Lošinj – Zadar
KORČULA	T633	Ploče – Trpanj
LASTOVO	T634	Dominče – Orebić
	T633	Ploče – Trpanj
LOŠINJ	T332	Valbiska – Merag
	T334	Brestova – Porozina
MLJET	T633	Ploče – Trpanj
OLIB	T332	Valbiska – Merag
	T334	Brestova – Porozina
OŠLJAK	B409	Zadar – (Ošljak) – Preko
PAŠMAN	T431	Zadar – Preko
	B409	Zadar – (Ošljak) – Preko
PREMUDA	T332	Valbiska – Merag
	T334	Brestova – Porozina
RIVANJ	T431	Zadar – Preko
	B409	Zadar – (Ošljak) – Preko
SESTRUNJ	T431	Zadar – Preko
	B409	Zadar – (Ošljak) – Preko
SILBA	T332	Valbiska – Merag
	T334	Brestova – Porozina
SRAKANE VELE	T401	Mali Lošinj – Zadar
	T332	Valbiska – Merag
	T334	Brestova – Porozina
SUSAK	T332	Valbiska – Merag
	T334	Brestova – Porozina
	T401	Mali Lošinj – Zadar
UGLJAN	T432	Biograd – Tkon
UNIJE	T332	Valbiska – Merag
	T334	Brestova – Porozina
	T401	Mali Lošinj – Zadar

3.3.1. Beneficiaries of the right to transport at a discount

Based on the interpretation of the Ordinance, the right to privileged transport includes reduced-price transport and free transport. Beneficiaries of the right to discounted transportation are: [6]

1. children aged 3 to 12 years

2. vehicles and vehicles of lessees residing on the island and registered with the competent administrative body in the Republic of Croatia
3. vehicles of legal entities, i.e. vehicles registered for tradesmen, family businesses, freelance activities and lessees with the registered office of the vehicle user on the island and the vehicles registered with the competent administrative body in the Republic of Croatia
4. employees of the public health service and employees of other public services (police, armed forces, fire brigade, port authority) whose permanent place of work is on the island and their service vehicles used on the island,
5. employees of the public health service and their service vehicles if they provide regular transport of patients from the island to the mainland and vice versa,
6. other persons who acquire this right according to special regulations.

3.3.2. Beneficiaries of the right to free transport

Beneficiaries of the right to free transport in the coastal liner passenger transport of the Republic of Croatia are: [6]

1. pupils and students residing on the island who travel daily to a school or college outside the island,
2. pupils and students residing on the island who temporarily stay outside the island during the school period and come to the island on weekends,
3. children attending compulsory pre-school off the island of their residence, as well as pupils and students studying on the island of their residence and children attending pre-school on the island of their residence for activities off the island of their residence,
4. children aged one to three years,
5. retired persons and persons over 65 years of age residing on the island,
6. employees of the Public Health Service and their service vehicles when carrying out medical transport from the island to the mainland and vice versa,
7. police officers and their service vehicles when carrying out their duties on the islands,
8. employees of other public services (police, armed forces, fire brigade, port authority and GSS) and their service vehicles during disasters and emergencies, as well as search and rescue operations, with the consent of Coastal Shipping Agency, granted at the request of the payer, in accordance with the special regulations for protection against natural disasters and accidents.

The right to privileged transport at the state borders is realized by the users based on the Island Card for Maritime Passenger Transport, Island Card for Maritime Transport of vehicles and vignettes, student documents and issued tickets, unless Ordinance provides otherwise for certain categories of users.

A reduction of up to 50% of the regular ticket price is granted for reduced-price transport. The amount of thediscount for the users referred to in Article 2, paragraph 2 of the Ordinance shall be determined by the Management Board of the Coastal Shipping Agency when setting the maximum level of the price for public transport services with a public service obligation.

For the vehicles referred to in Article 2, paragraph 2, item 3 of the Ordinance, the right to a reduced fare for one return journey per day may be realized on all ferry lines connecting the owner's or user's island of residence with the mainland or any other island applicable to the island. residence of a natural person.

For the vehicles referred to in Article 2, paragraph 2, point 4 of the Ordinance, the right to a reduced fare may be realized on an unlimited number of journeys per day on all ferry lines connecting the island of residence of legal entities, traders, family businesses, with the mainland or another island applicable to the island of residence of the company.

3.4. Analysis of categories of passengers and personal vehicles used in the formation of tariffs in the RH

The main characteristic of passenger transport on the coastline in the Croatian part of the Adriatic is significant seasonal fluctuations resulting from unequal tourist demand during the calendar year. The dominant shipping company on the Croatian market, Jadrolinija, distinguishes between off-season and seasonal prices, which are the result of changes in transport demand. A more detailed overview of the categories and methods of tariff formation is shown below on the example of ferry line 335, one of the most frequent national lines in coastal liner transport of Republic of Croatia which in 2019. Had a total number of 917.942 passengers and 342.363 vehicles [12] .

Table 3 Example of ticket price on the national ferry line no. 335 Prizna - Žigljen. [13]

CATEGORY	OFF-SEASON	SEASON	ISLANDERS	PUBLIC SERVICES
Children from 0 to 3 years	0 KN	0 KN	0 KN	0 KN
Children from 3 to 12 years	7 KN	8,50 KN	0 KN	0 KN
Elderly + 12 years	14 KN	17 KN	7 KN	9 KN
Vehicles shorter than 5 m	80 KN	96 KN	48 KN	48 KN
Vehicles longer than 5 m	134 KN	161 KN	81 KN	81 KN

In addition, there are 2 categories of vehicles, shorter and longer than 5 meters, and for vehicles longer than 5 meters and / or higher than 2 meters, a 40% higher price is paid. Season ticket prices are on average 16% higher than out of season. Children aged 0-12 years who have a residence or stay on the travel island or belong to a public service do not pay tickets. Persons over 12 years of age who have a residence on the island or belong to a public service pay an average of 50% of the ticket price. Vehicles belonging to island residents or public services also pay 50% of the ticket price, and the island fare list is valid all year round.

The off-season fare list is valid for the period 01.01. - 03.06.2021. and 04.10. - 31.12.2021, and seasonally from 04.06. - 03.10.2021. The island fare list and the public service fare list are valid all year round. Children up to 1 year of age travel free of charge and do not receive a ticket, but the parent/guardian card indicates that the person is traveling with a child up to 1 year of age. Children ages 1 to 3 also travel free but receive a ticket. Children 3-12 years old pay half the ticket price, while adults (+12) pay full ticket price without benefits and carry-on baggage is not charged.

4. COASTAL LINER PASSENGER TRANSPORT OF THE REPUBLIC OF CROATIA IN COMPARISON TO THE OTHER EUROPE COUNTRIES

According to the latest Eurostat data, maritime passenger transport in Europe is mainly carried out by national ferry services, with the same passengers being statistically recorded twice, once when boarding a ferry in an EU port and the second time when disembarking from the same ferry in another EU port. In 2013 Italian and Greek ports accounted for more than one-third of EU-28 maritime passenger transport. Italy accounted for 18.32% (73.24 mil.) and Greece for 18.24% (72.92 mil.) of total EU-28 maritime passenger transport (399.67 mil.) [14]. With 86.5 million and 73.9 million maritime passengers respectively, ports in Italy and Greece together accounted for 38.5% of the total number of passengers embarked and disembarked in EU ports in 2019 (Chart 1). The graph shows that Italy and Greece remain the leading countries in terms of maritime passenger transport in the EU, which is why they are considered relevant countries when comparing the categories of passengers and vehicles in liner shipping with those of the Republic of Croatia [15].

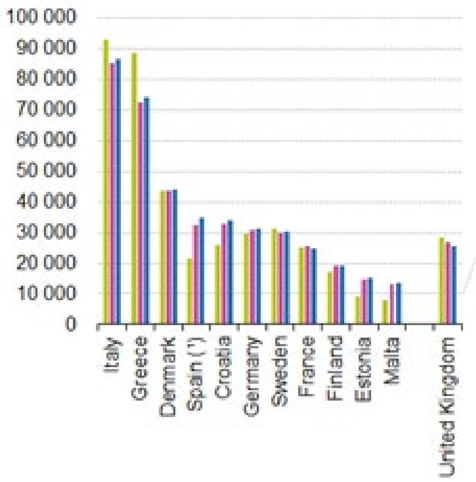


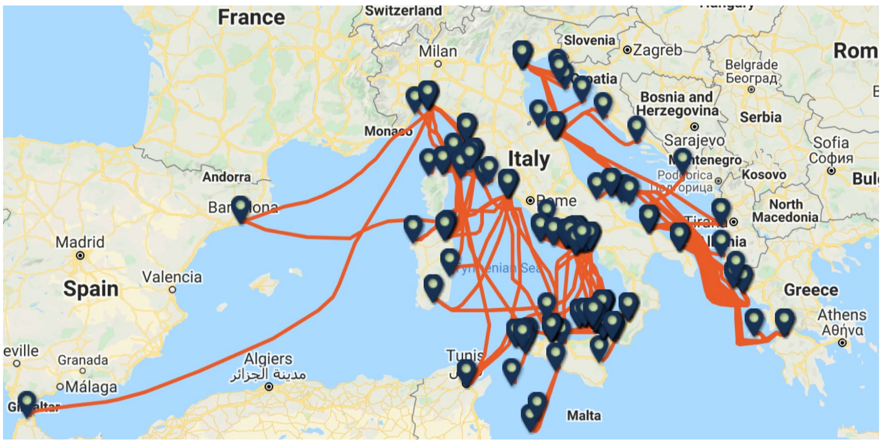
Chart 1 Leading countries by number of passengers in the EU in 2009, 2018 and 2019 (in thousands) [15]

From the data presented in Chart 1, it can be concluded that Italy and Greece dominate the European market for maritime passenger transport. Furthermore, according to Eurostat data, if cruise passengers are excluded, Italy and Greece also lead in maritime passenger transport, both in total transport and in domestic transport only. Considering the fact that in the Republic of Croatia there is no defined way of setting tariffs or a detailed way of dividing the category of passengers and vehicles, the categories applied by Italian and Greek ferry operators are analyzed below in order to improve the existing model applied in Croatia.

The selected countries resemble Croatia in their climatic and geographical characteristics. They have a highly indented coastline, especially Greece, and the ferries that sail on their territorial seas must have similar specifications for undisturbed navigation as those used in the Croatian coastal area.

4.1. Ferry operators in the coastal liner passenger transport of Italy

Italy is a country with a long maritime tradition and has been a leader in coastal liner passenger transport for years. There are many ferry companies operating ferry routes in Italy, as well as Italy's connections with other countries such as France, Greece and or Croatia. There is currently a wide range of ferries connecting Italy to over 28 destinations, and ferries sail weekly from various ports around the world to other ports in Italy. The lines are shown on map 1.



Map 1 Italian Ferry Lines[16]

There are a total of 208 national and international routes served by 26 different shipping companies, and there are 101 national ferry routes served by 17 shipping companies, some of which are listed in Table 4.

Table 4 Share of total ferry transport of Italy of selected ferry companies [17]

CARRIER	NUMBER OF ROUTES	SHARE
Siremar	64	51.20%
Snav	8	6.40%
Caremar	9	7.20%
Tirrenia	8	6.40%
Torremar	4	3.20%
Gnv	8	6.40%
Grimaldi Lines	7	5.60%
Corsica Ferries	5	4.00%
Moby	5	4.00%
Medmar	4	3.20%
Positano Ct	2	1.60%
Blu Navy	1	0.80%

Table 4 shows the share of each shipping company in the total traffic on Italian ferry lines. The largest ferry company is Siremar with 64 routes and a 51.20% share of the total number of routes. It is important to note that there are 101 different lines served by 1 or more shipping companies. For example, the Piombino-Portoferraio line is served by as many as 4 shipping companies: Corsica Ferries with 21 lines per week, Moby with 84 lines per week, Torremar with 147 lines per week and Blu Navy with 56 lines per week. The categories and types of tariff formation in Italy are analyzed below.

4.1.1. Analysis of the categories of passengers and personal vehicles used in the formation of tariffs in Italy

The categories of passengers and passenger vehicles used in the formation of tariffs for three ferry operators operating in the coastal area of Italy are analyzed below. The tables are prepared according to the available data from Siremar, Tirrenia and Medmar [18]–[20].

Table 5 Categories of passengers used for the formation of tariffs in Italy's coastal liner passenger transport

CATEGORY	SIREMAR	TIRRENIA	MEDMAR
Children under 1 year	NO	YES	NO
Children from 1 / 0-3 / 4 years	YES	YES	YES
Children from 3 / 4-11 / 12 years	YES	YES	YES
Elderly + 12 years	YES	YES	YES

Table 5 lists the passenger categories according to which the Italian ferry operators Siremar, Tirrenia and Medmar define their tariffs. All analyzed ferry operators have defined tariffs for 3 categories among passengers, as is the case with Jadrolinija. Children are divided into two categories at Siremar ferry company, i.e. children aged 0-3 and 04-11. Medmar also divides them into 2 categories, while Tirrenia divides them into 3. In Medmar, the first category refers to children from 0-3 years old and the second from 3 to 12 years old, Tirrenia has an additional category for children up to 1 year old, while the other 2 categories are the same as in Medmar. Unlike the Greek carriers that will be shown below, the Italian carriers do not have such detailed categories for passengers.

Table 6 Categories for passenger cars used to form tariffs in Italian coastal liner passenger transport.

CATEGORY	SIREMAR	TIRRENIA	MEDMAR
Vehicles up to 3.5 m	X		
Vehicles up to 4 m	X	X	X
Vehicles up to 4.5 m	X		X
Vehicles longer than 4.5 m	X		X
Vehicles from 4.01 to 5 m		X	
Vehicles longer than 5.00 m		X	

In contrast to Jadrolinija, the shipping companies Siremar, Medmar and Tirrenia use different categories in the formation of tariffs for passenger cars in coastal liner transport. Siremar distinguishes the largest number of categories, namely 4 as follows: nehicles up to 3.5 m, vehicles up to 4 m, up to 4.5 m and vehicles over 4.5 m. Carriers Tirrenia and Medmar distinguish one category less and divide vehicles into 3 groups. Tirrenia in categories: vehicles up to 4 m, from 4.01 to 5 m in length and longer than 5 m. While Medmar divides them into categories similar to Siremar: vehicles up to 4 m, up to 4.5 m and longer than 4.5 m.

4.1.2. Analysis of discounts by categories in Italian coastal liner passenger transport

Starting from based adult category (+12, i.e. +11 years), which is the starting point for determining the tariffs, it is possible to analyze the discounts that passengers in the other categories receive.

Table 7 Discounts for passengers and vehicles by category in Italy

CATEGORY	DISCOUNT		
	SIREMAR	TIRRENIA	MEDMAR
Children from 0-3 / 4 years	80%	100%	70%
Children from 3 / 4-12 years	40%	50%	40%
Elderly + 11/12 years	0%	0%	0%
Vehicles up to 3.5 m	0%	-	-
Vehicles up to 4 m	0%	0%	35%
Vehicles up to 4.5 m	0%		15%
Vehicles longer than 4.5 m	0%		0%
Vehicles longer than 4.01 to 5 m		0%	
Vehicles 5 m long		0%	

As shown in Table 7, children under 3 years of age are entitled to free transport in two of the three transport companies analyzed, so in the case of the Siremar transport company, children aged 0-3 years pay for the ticket in the low season. The only case where children aged 0-3 do not pay for a ticket when using the ferry of the carrier Siremar is when they are residents of the island. For the second category of passengers, children aged 4-11 years, a 40% discount is granted. Siremar distinguishes 4 categories of vehicles, but applies the same price for all, only a 50% discount is charged when it comes to residents. Like Jadrolinija, Siremar distinguishes between seasonal and low season tariffs and offers the possibility to buy discounted tickets for island residents, but not for public service. Siremar allows island residents to buy a 55% cheaper ticket, but unlike Jadrolinija, which allows children from 3 to 12 to travel for free, Siremar charges them tickets at a 40% discount compared to the group of passengers aged 11 and over. Siremar also charges islanders different discounts depending on the vehicle group. Island vehicles shorter than 3.5m are charged a 69% discount, while vehicles longer than 4.5m are charged a 38% discount. In addition, Siremar offers a category of excursion groups in which users who buy a larger number of tickets can receive a certain discount on the amount agreed with the carrier. On Siremar's lines, passengers staying on small islands can receive discounts through a special "Resident" price list.

In analyzing the carrier Tirrenia tariffs are formed depending on the category of passengers and thus distinguish 4 categories, of which for the first two, ie, children up to 1 year and children from 1 to 4 years are always free. For the third category, children from 4 to 12 years old are given a 50% discount, while those over 12 years old pay the full price of the ticket. At Tirrenia, the discount is not calculated regardless of the length of the vehicle. The Tirrenia special discount is calculated for all 3 categories of vehicles if they are residents-only vehicles. Tirrenia also offers discounts for residents of Sardinia, Sicily and the island of Tremiti.

Carrier Medmar has both passengers and vehicles are divided into 3 categories, each of which pays a certain amount for transportation, and vehicles are differentiated into 3 categories instead of 2 as in Jadrolinija. For the 1st category of passengers, children from 0-4 years old, whether they live on the island or not, pay 72% less for the ticket. Children from 3-12 years old have 40% discount. Medmar distinguishes 3 vehicle categories, and the fare difference between the shortest and the longest vehicle category is 35%. Medmar offers special discounts for residents of Ischie and Procidia..

4.2. Ferry operators in the coastal liner passenger transport of Greece

Greek coastal liner passenger transport is the largest shipping market in Europe, accounting for 16.9% of the total Volume. With 143 ports that are ferry ports, Greece has the densest network of ferry ports in Europe [21]. Between 17 and 19 shipping companies operate in the Greek ferry market, with some of them also forming groups. Following the liberalization of coastal ferry services in 2002, the market structure has not changed significantly. A limited number of operators, usually maximum of two per line on the main markets, indicates the existence of an oligopolistic market structure [22]. On the main lines, the transport activity is carried out by 11 shipping companies, so it is possible to speak of an extensive concentration of the sector.

Map 2 Greek Ferry Lines [23]

Greece also has the largest number of maritime passengers in Europe. The fact that it covers 18% of European passenger demand for RO -RO transport services, despite representing only 2.2% of the European Union population, implies that passenger demand in Greece has unique characteristics that distinguish it from other European countries [24]. The system is characterized by high seasonality caused by uneven tourism demand throughout the year [25]. One third of the annual turnover is realized in the summer months. In the low season, passenger traffic is limited, so that the operation of coastal shipping companies depends mainly on truck transport.

The value of the ferry ticket is directly related to the ferry operator's pricing policy. The price of a ticket charged to passengers depends on a number of variables, such as:[25]

1) route (including the level of competition in the ferry market or with other modes of transport and berths in ports).
2) type of passenger accommodation (e.g. cabin or seat).
3) category of accompanying vehicle (e.g. sorted by length)
4) season (summer / winter).

Regardless of whether the traveler buys a ticket in Greece, in another European country, or in another country in the world, the price of the ticket is always the same. The price may include discounts based on some specific rights, but these discounts are defined and apply to those affected by certain criteria, regardless of where they booked the ticket [25]. Since the countries leading in the number of passengers carried are used as an example for the analysis of tariff formation and division of categories in liner shipping, in addition to Italy, Greece is also analyzed below.

4.2.1. Analysis of the categories of passengers and personal vehicles used in the formation of tariffs in Greece

The following section analyzes the categories of passengers and personal vehicles used in the formation of tariffs for three ferry operators operating in the coastal area of Greece. The following tables are based on available data from Blue Star Ferries, Hellenic Seaways and Thassos Ferries [26]–[28].

Table 8 Categories of passengers used to form tariffs in the Greek coastal liner passenger transport

CATEGORY	BLUE STAR FERRIES	HELLENIC SEAWAYS	THASSOS FERRIES
Children up to 5 years	YES	YES	YES
Children from 5 to 10 years	YES	YES	YES
Teenagers (11-17 years)	YES	NO	NO
International Student Identity Card "ISIC" holders	YES	YES	YES
Students of Greek universities	YES	YES	YES
Adults (25 - 60 years)	YES	YES	YES
Unemployed adults	NO	NE	YES
Older people (60+ years)	YES	SOMETIMES	NO
Excoursion groups	YES	YES	YES

Table 8 lists the passenger categories used by the Greek ferry operators Blue Star Ferries, Hellenic Seaways and Thasssos Ferries to define fares. All analyzed ferry operators have defined tariffs for the categories: children up to 5 years old and children from 5 to 10 years old. The company Blue Star Ferries offers the teenager category (11-17 years) to the buyer when purchasing a travel ticket. This category is primarily used to determine whether unaccompanied minors have parental consent to travel. In addition, the companies studied distinguish between International Student Identity Card "ISIC" holders and students of Greek universities as special categories of travelers. The basic category that determines the ticket price for all analyzed companies is the adult category (25-60 years old). Thassos Ferries highlights unemployed people as a special category, while the other two operators do not specify this category when purchasing tickets. All three analyzed ferry operators offer a category of the excursion group, where users who buy a larger number of tickets can get a certain discount on the quantity. In addition, the Greek ferry operators also distinguish between seat types in the liner coastal passenger transport. The shipping company Blue Star Ferries divides them into Economy Lounge, Air seats (Economy) and Business Lounge, which creates the possibility to generate higher revenues depending on the travel comfort.

Table 9 Categories for passenger cars used for the formation of tariffs in Greece

CATEGORY	BLUE STAR FERRIES	HELLENIC SEAWAYS	THASSOS FERRIES
Cars (up to 4.25 m)			X
Cars (over 4.25m)			X
Vehicles less than 6 m long and less than 2 m high		X	
Vehicles longer than 6 m and higher than 2 m		X	
A unique category for all cars	X		

Blue Star Ferries, Hellenic Seaways and Thassos Ferries use different categories when defining the price of passenger vehicles in coastal liner transport. Thassos Ferries distinguishes the categories passenger cars up to 4.25 m and passenger cars over 4.25 m. Hellenic Seaways also differ two categories for passenger cars, but in addition to the length of the vehicle, the width is also given as a criterion for each category. Therefore, the categories are vehicles under 6 m in length and under 2 m in height and vehicles over 6 m in length and over 2 m in height. Blue Star Ferries applies a unique category to all vehicles, regardless of their height and width. Unlike the Italian carriers that were shown before, the Greek carriers do not have such detailed categories for cars.

4.2.2. Analysis of discounts by category in Greek coastal liner passenger transport

Starting from the adult category (25-60 years old), which is the starting point for determining the fare, it is possible to analyze the discounts that passengers of other categories receive; the discounts are presented in Table 10 and are explained below.

Table 10 Discounts for passengers by category

CATEGORY	BLUE STAR FERRIES	HELLENIC SEAWAYS	THASSOS FERRIES
Children up to 5 years	100 %	100 %	100 %
Children from 5 to 10 years	50 %	50 %	50 %
International Student Identity Card "ISIC" holders	50 %	50 %	50 %
Students of Greek universities	50 %	50 %	50 %
Adults (25 - 60 years)	0	0	0
Unemployed adults	Not defined	Not defined	20 %
Older people (60+ years)	10 %	Not defined	Not defined
Excoursion groups	On request	On request	30- 50 % per person

Children up to 5 years of age are entitled to free transportation on all three shipping companies analyzed, while the ticket price for the category of children from 5 to 10 years of age is 50% of the ticket price for adults. International Student Identity Card "ISIC" holders and students of Greek universities, whether they travel with Blue Star Ferries, Hellenic Seaways or Thassos Ferries, pay 50% of the ticket price.

Unlike the other carriers, Thassos Ferries offers a 20% lower ticket price for the category Unemployed Adults. For people over 60, Blue Star Ferries offers a 10% discount on the ticket price, while Hellenic Seaways gives them a discount on certain routes and in varying percentages compared to the adult category ticket price. The companies also provide discounts for excursion groups. Groups that choose to use the services of a Blue Star Ferries or Hellenic Seaways operator send a request, based on which the price is then determined. Thassos Ferries offers excursion groups a discount of 30-50% per person, depending on the route traveled and the size of the group. In addition to the above categories, Blue Star Ferries also offers discounts on certain routes as well as 20-25% lower prices for people aged 13-25 and discounts for family trips.

5. CONCLUSION AND DISCUSSION

For the Republic of Croatia, which has a highly indented coastline and many inhabited islands, passenger transport on lines connecting the islands with the mainland and the islands with each other is of the most importance. Passenger transport is provided on predetermined lines on which the price, offer, conditions of travel and discounts are fixed, and passengers cannot claim ignorance of the conditions of travel or prices, since the data are publicly known and they can access them at any time. If necessary, additional vessel capacity may be hired during the summer months due to increased demand for transportation, in addition to the regular lines that operate throughout the year.

Based on the data obtained and the market analysis, the following SWOT analysis was prepared as a starting point for strategic considerations on how to improve Jadrolinija's tariff model. After analyzing the main strengths, weaknesses, opportunities and threats, proposals were made to change the tariff model of Jadrolinija. The analysis of the obtained research results as the main strengths and weaknesses (internal factors) and opportunities and threats (external factors) show:

Table 11 SWOT analysis of Jadrolinija’s tariff model

STRENGTHS	WEAKNESSES
- Dominant carrier on the Croatian market - Annual growth in the number of passengers and vehicles on the ferry routes - A large number of daily connections between the coast and the islands - Competence of the staff - High quality of transport service - Online ticket sales system - Partner in EU projects	- Impossibility to set the price of tickets completely independently - High maintenance costs - Insufficiently significant changes in tariffs - Obligation to provide public service regardless of demand - Inconsistency of business policy and changes on the market - Poor marketing - Low level of computerization - Slow adaptation to market changes
OPPORTUNITIES	THREATS
- Greater state incentives - Recognition of Croatia as a tourist destination - Slight increase in population on the islands - Investments in new technologies - Development of the islands - EU funds	- Fluctuation of various micro and macroeconomic indicators - Various negative influences on transport (e.g. wars, pandemics, natural disasters, etc.) - Under-utilization of the island's economic capacity - Entry of foreign shipping companies into the Croatian market - Depopulation

The value of the ferry ticket in Greek and Italian maritime transport is directly related to the pricing policy of the ferry operator. The price of a ticket charged to passengers depends on a number of variables such as: route (including the level of competition in the ferry market or other modes and berths in ports), type of passenger accommodation for passengers (e.g. cabin or seat), category of accompanying vehicle (e.g. sorted by length) and season (summer/winter). These variables are used not only by Greece and Italy but also by other European countries. By analyzing the pricing in the coastal liner shipping of Greece and Italy, it is also possible to see how their operators apply revenue management, which has been present in air traffic for many years. If this principle were to be introduced in the Republic of Croatia, it could increase demand for costal liner passenger transport and allow Croatian operators to earn higher revenues. T If the demand for transport services increases, and with it the number of visitors to the island, this could lead to higher demand for all other services that are important for the economic development of the Croatian islands (e.g. hospitality, catering, trade ...).

Based on the analysis of the shipping companies operating on the territory of Greece, it is proposed to design a categorization of passenger tariffs in Croatian coastal liner transport depending on the age group, as applied by the shipping company Blue Star. Blue Star divides passengers into the following categories: children (up to 4 years), children, (4 -10 years), teenagers (11-17 years), adults (18 - 60 years), elderly (61+ years). It is also proposed to introduce a discount on tickets for excursion groups. This would increase the interest of travel agencies, which in this case would choose ferry transport more often than some other types of transport.

Moreover, based on the analysis of the shipping companies operating in Italy, it is suggested that in Croatian coastal liner passenger transport tariffs are set differently according to the age group, as applied by the shipping company Medmar. Medmar divides passengers into the following categories: children (up to 4 years), children (4 -12 years), adults (+12 years). The biggest difference between the current ticketing system and the proposal is that children up to 4 years old will have to pay one ticket, but with a discount and the 2nd category (children 4-12 years old) will be discounted with a lower percentage than they currently are.

Also, the introduction of an additional category for vehicles depending on the length would have a positive impact on the company's profit. Thus, instead of the current 2 categories (up to 5 meters and over 5 meters), personal vehicles would be divided into 3 categories, as is the case with Medmar: vehicles up to 4 meters, vehicles from 4 to 4.5 meters and vehicles over 4.5 meters. Dividing a current category (vehicles up to 5 meters) into 3 new ones would facilitate the change of ticket prices, thus allowing a fairer payment system for personal vehicles, as most personal vehicles are between 4 and 5 meters long.

In addition, it was noted that Greece and Italy do not have a privileged rate for public services and the Republic of Croatia introduced it only in 2017, so the need to reintroduce a specific fare card for public services needs to be assessed.

In conclusion, given the different seating categories observed among Greek carriers, it is suggested that in the future, when procuring new vessels, efforts should be made to procure ferries offering different seating categories.

LITERATURE

[1] Hrvatski Sabor, "Zakon o izmjenama i dopunama Zakona o prijevozu u linijskom i povremenom obalnom pomorskom prometu", Zagreb, NN 56/2016P. Prometu, "Hrvatski sabor 1448," 2016.
[2] Hrvatski Sabor, "Zakon o izmjenama i dopunama Zakona o prijevozu u linijskom i povremenom obalnom pomorskom prometu", Zagreb, NN 80/2013L. I. Povremenom, O. Pomorskom, and O. P. Prometu, "Hrvatski sabor 1673," vol. 2013, 2013.
[3] Hrvatski Sabor, "Zakon o prijevozu u linijskom i povremenom obalnom pomorskom prometu," Zagreb, NN 33/2006H. Sabor, "Zakon o prijevozu u linijskom i povremenom obalnom pomorskom prometu," Zagreb, 2006..
[4] A. Jugović, D. Aksentijević, and P. A. Zaninović, "The impact of economic policy on shipper businesses in coastal line maritime passenger transport in Croatia," vol. 35, pp. 87–92, 2021.
[5] R. Zelenika, "Primarne prometne tarife", Rijeka, Ekonomski fakultet, IQ PLUS, 2009.
[6] R. Zelenika, "Sekundarne prometne tarife", Rijeka, Ekonomski fakultet, 2009.
[7] R. Zelenika, M. Zanne, and E. Twrdy, "Tariffs as a tool for successful operation of shipping companies | Tarife u funkciji uspješnosti poslovanja pomorskih brodara," *Nase More*, vol. 55, no. 5–6, pp. 182–190, 2008.
[8] R. Varela, H. Murphy, and M. Linden, van der, *Shipbuilding and Ship Repair Workers around the World. Case Studies 1950-2010*. 2017.
[9] M. Š. Č. Ivaković, R. Stanković, *Špedicija i logistički procesi*. Zagreb: Fakultet prometnih znanosti, Sveučilište u Zagrebu, 2010.
[10] P. Mandić, Nikola; Amižić Jelovčić, "Novine u Zakonu o prijevozu u linijskom i povremenom obalnom pomorskom prometu iz 2013. godine," *Pored. Pomor. pravo*, vol. 53, no. 168, pp. 127–142, 2014.
[11] M. Mora, P. I. Infrastrukture, and J. P. Prijevozu, "Pravilnik o uvjetima i načinu ostvarivanja prava na povlašteni prijevoz na linijama u javnom pomorskom prijevozu," vol. 2017, no. 3, 2017.
[12] AZOLPP, "Promet putnika i vozila na državnim linijama," pp. 1–4, 2018, [Online]. Available: http://agencija-zolpp.hr/wp-content/uploads/2019/04/PROMET_PUTNIKA_I_VOZILA_2017-2018.pdf.
[13] AZOLPP, "Državna trajektna linija br. 355"", 2019, [Online]. Available, https://agencija-zolpp.hr/wp-content/uploads/2019/04/335-Prizna-Zigljen-1.pdf..
[14] V. Stupalo, A. Jugović, and A. Mrvica, "Kvantitativna analiza pomorskog putničkog prometa u Europi," *Nase More*, vol. 63, no. 4, pp. 256–263, 2016, doi: 10.17818/NM/2016/4.2.
[15] "Maritime passenger statistics - Statistics Explained." https://ec.europa.eu/eurostat/statistics-explained/index .php?title=Maritime_passenger_statistics&oldid=514192#Number_of_seaborne_passengers_reaches_419_million (accessed Jul. 20, 2021).
[16] "Ferries to Italy - Compare ferry routes and prices." https://www.directferries.com/italy.htm (accessed Jul. 07, 2021).

[17] "Ferry tickets to Greek Islands, Spain, Italy & Turkey | Ferryhopper." https://www.ferryhopper.com/en/ (accessed Jul. 07, 2021).
[18] "Medmar | La nave per Ischia | Biglietteria on line." https://www.medmargroup.it/index.php?route=booking2/data (accessed Jul. 08, 2021).
[19] "Traghetti e navi Tirrenia: offerte e prenotazioni sul sito ufficiale." https://www.tirrenia.it/ (accessed Jul. 08, 2021).
[20] "Traghetti da e per la Sicilia | Siremar." https://carontetourist.it/it/siremar (accessed Jul. 08, 2021).
[21] M. El-Dairi and R. J. House, "Optic nerve hypoplasia," *Handbook of Pediatric Retinal OCT and the Eye-Brain Connection*. pp. 285–287, 2019, doi: 10.1016/B978-0-323-60984-5.00062-7.
[22] M. Lekakou, G. Remoundos, and E. Stefanidaki, "Corporate Partnership Board CPB Applying the Island Transport Equivalent to the Greek Islands Discussion Paper," 1931. Accessed: Jul. 08, 2021. [Online]. Available: www.itf-oecd.org.
[23] "Flights and ferries to Greece & Turkey." https://www.sailingissues.com/yachting-guide/flights-ferries.html (accessed Jul. 08, 2021).
[24] "The beginning of a new cycle with 'countermeasures,'" 2018. https://xrtc.gr/wp-content/themes/html5blank-stable-child/reports/XRTC Ferry Report 2018 EN.pdf (accessed Jul. 07, 2021).
[25] M. Brambilla and A. Martino, "DIRECTORATE GENERAL FOR INTERNAL POLICIES POLICY DEPARTMENT B: STRUCTURAL AND COHESION POLICIES TRANSPORT AND TOURISM Research for TRAN Committee-The EU Maritime Transport System: Focus on Ferries STUDY."
[26] "Thassos Ferry Schedules & Ticket Prices | Go Thassos." https://www.go-thassos.gr/thassos-ferry-schedules-prices (accessed Jul. 08, 2021).
[27] "Αρχική." https://www.bluestarferries.com/ (accessed Jul. 08, 2021).
[28] "New reservation." https://www.hellenicseaways.gr/en-gb/booking?br=lI_0P-X-RhVl7YlS2ZUrf8a_VoBBOEQ5MEM0MEU0RDU4NjI1fDF8MXwxfFRydWV8R1I6SEVSfEdSOlBJUnwyMDIxMDYxOHxHUjpQSVJ8R1I6SEVSfDIwMjEwNjE5 (accessed Jul. 08, 2021).

MAIN BEARING MAINTENANCE AND CRANKSHAFT DEFLECTION MEASUREMENTS BY APPLICATION OF AMOT AND DI - 5C SYSTEMS

Mate Jurjević
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: mate.jurjevic@unidu.hr

Nives Vidak
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: nives.vidak@unidu.hr

Damir Mičić
E-mail: mico_damir@yahoo.com

UDK 621.822 :004.4

Abstract

In the thesis the bearings maintenance system and wear measurements are analysed. Continuous and dedicated efforts of engineers have led to improvements of this system as it has evolved from manual measurements and use of old tools and measurement instruments to a sophisticated software for precise measurement and alerting. Along with technological advances, in an effort to make improvements and prevent failures and/or damages, the monitoring and measurement systems of this fundamental part of marine engines have been developed. The need for safer, higher quality and more reliable measurements of bearing wear has led to development of software providing such services on the market for engineers all over the world. These systems have also been improved and upgraded in accordance with the ship owners' requirements, depending on the type of ship and requirements of the crew involved. AMOT system is the type of software enabling complete control over the bearing condition, wear and monitoring of all parameters directly on the screen. Furthermore, one of the advantages of the system is flexible installation, arrangement of monitoring units and installation of sensors. Moreover, special attention has been paid to monitoring bearing wear as well as measurements, both manually and by application of AMOT system within a period of time. Due attention has been given to the very AMOT system as well, installation, operation, handling, options and requirements for instalment, sensors, i.e. their installation and arrangement. Attention has also been given to the crankshaft, crankshaft deflection and deflection measurements, as well as correlation between deflection and bearing wear. Since in maritime industry the correlation between crankshaft deflection and bearing wear is well known, due attention has been given to taking and recording measurements as well as their calculations in order to reduce or prevent these two occurrences that have been happening ever since the invention of internal combustion engines. Nevertheless, as the sophisticated monitoring system is analysed, parts of AMOT system have been included in the analysis as well as system interface, signal processing unit, dimensions and technical characteristics.

Keywords: maintenance, crankshaft, bearings, Diesel engine, maintenance software

1. INTRODUCTION

AMOT XTS-W2 is a sophisticated system for monitoring condition and wear of internal combustion marine engine bearings. The system consists of sensors installed in the engine, signal processing unit, interface that can be installed anywhere on board, computer, water in oil sensor with the control unit and crankshaft monitoring system with control unit.

The system is made to provide all required values and parameters instantly and it is simple to use and store data. The system consists of hardware and software. It can be installed at the ship-owner's discretion anywhere in the engine room, on the engine and inside the engine. This system is used to monitor condition of engine bearings.

DI – 5C system is a system consisting of hardware and software. It is used to measure crankshaft deflections and obtain data in the system software.

2. AMOT SYSTEM

AMOT system consists of hardware and software. The usage of the system on board ships worldwide is constantly increasing and additional options of the system are being made to be integrated as both additional and serial equipment.

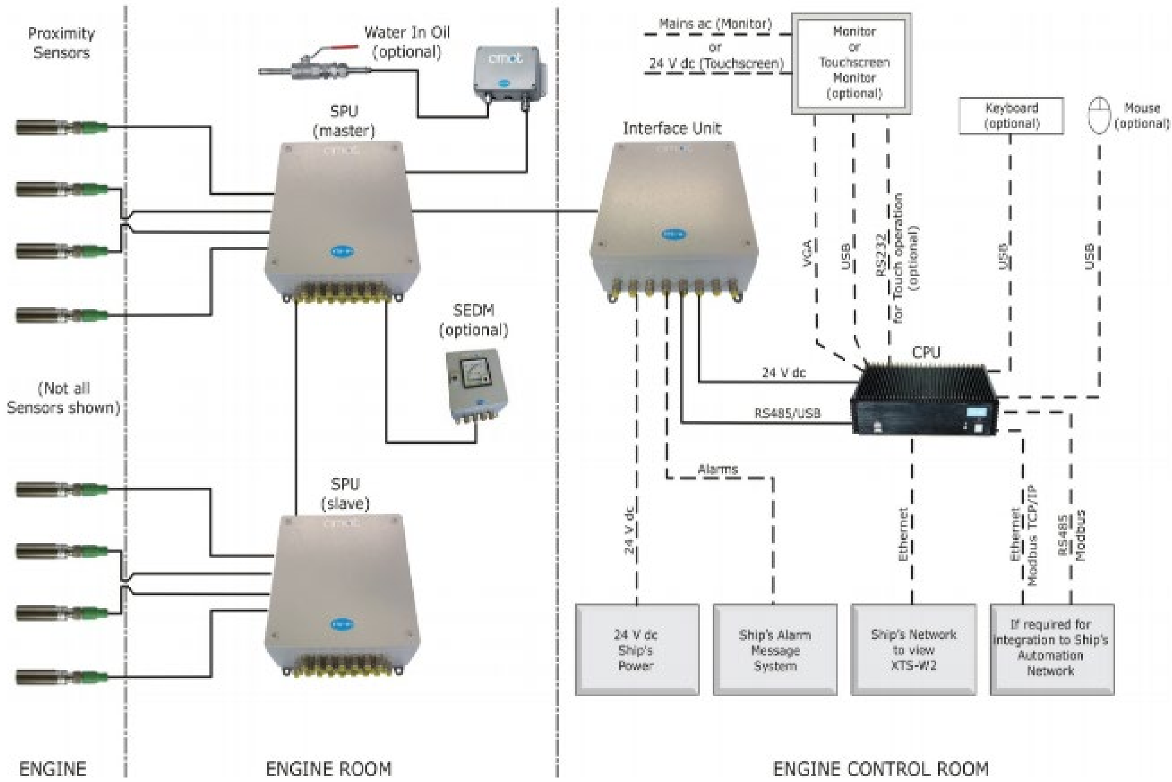


Figure 1 – AMOT system schematic view (Source: AMOT System Overview)

2.1. Hardware

Hardware of AMOT system comprises the following components: clearance sensors (installed in pairs into each cylinder), data processing unit with accompanying wires from the sensor, interface unit (with wires leading from data processing unit), computer and interface recording software interfaces and data obtained by sensor measurements, part of the standard equipment of this system and coming in the package with the product.

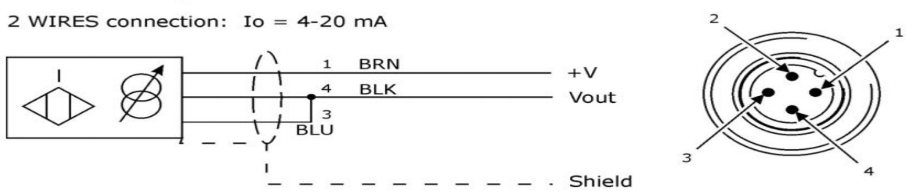
- CLEARANCE SENSORS

They are installed in the engine – two for each cylinder, while on the end bearings (the first and the last bearing) there is only one sensor installed (e.g. the bearing next to the engine flywheel or ship's generator). Sensor consists of a tube with threads along its length which enables the sensor to be brought closer or farther from the engine part being measured, depending on the distance stipulated by the manufacturer. This distance is set on the plate which makes a part of standard equipment of the system in order to position the sensors to the exact distance from the bearing being measured as thickness of the plate is identical to the required distance between the sensor and the bearing.

Sensor is shown in Figure 2 along with the schematic view showing the source of power for the sensor (Figure 1) and protection (Figure 2), as well as the two parts (Figures 3 and 4) enabling transfer of data recorded from the sensor to the data processing unit. Furthermore, each sensor has a carrier made according to the type of engine where the system is being installed and it is made for each type of engine separately to prevent hindrance in regular operation or engine damage.

Figure 2 - Image and schematic view of clearance sensor (Source: AMOT System Overview)

- DATA PROCESSING UNIT



Data processing unit is fed directly from the interface, thus installation of separate feed of 24 V is eliminated. This unit processes and stores data from the sensor into indelible memory and onto SD card. Data from the memory can be read from the data processing unit as well as from every computer on the ship's network. Data processing unit has inlets for 14 wear sensors as well as one inlet for water in oil sensor. In engines with more than 7 cylinders, another auxiliary unit ("SLAVE"), directly connected to the first unit ("MASTER") must be installed. From there the data processing unit is directly connected to the interface by (MULTI-CORE) wire.

- INTERFACE UNIT

Interface unit has independent 24 V feed with insulated outlet to supply the data processing unit. The interface is also fed from the interface unit, through a fuse, but the feed is not separate or insulated from other feeds as in the case with the data processing unit. In this unit there are three relays that provide outlets for connection to the ship's alarm system. These three relays have following outlets:

Regular (outlet under constant power supply while the bearing is within the green area, i.e. within bearing wear tolerance limit). Alarm outlet (yellow area that is not powered until the sensor indicates bearing wear exceeding green tolerance limit) and critical value outlet (red area powered only when the sensor indicates bearing wear that is critical and dangerous for safe work and other engine parts).

- COMPUTER

Computer is designed as a personal computer with power on/off button and USB ports in order to enable storage of data received from the sensor into various media via USB. The computer is at the same time the main source of data of this system. It is installed in the control room at the ship-owner's discretion and a possibility is provided for it to be connected via the ship's internet to other computers on board, making thus all recorded data available everywhere on board.

2.2. Software

System software consists of a number of interfaces. The interface shown in Figure 3 is the main software interface and it shows the status of connection of all system components in different colours. As shown in the Figure, green colour indicates that all system components are properly connected. During software installation, data on the ship is entered, i.e. ship's name, owner, software users, type, make and engine model, number of cylinders. Software detects and shows connection of hardware with the software. If there is an interruption in communication between individual parts of the system with the software, it will be shown in red or as prohibition sign across the main interface of the software. Furthermore, the software enables printing of bearing wear graphs as well as sensor operation deviations during engine operation as well as engine rpm. It also detects and prints the firing order of engine cylinders.

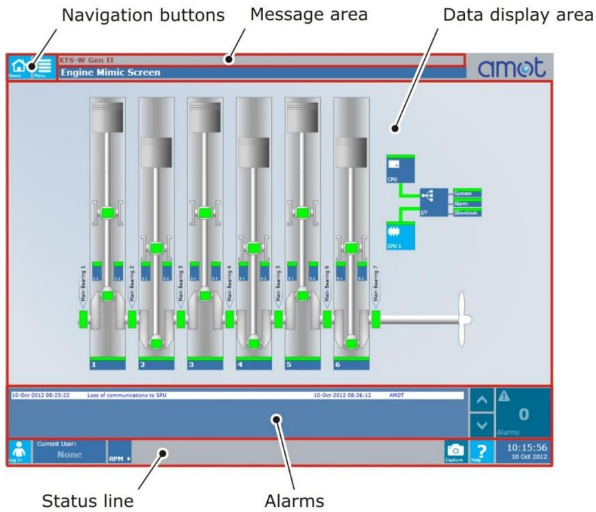


Figure 1 - AMOT system main software interface (Source: AMOT System Overview)

Sensors operation and bearings wear can also be shown in diagrams as columns in colours: green for normal wear within tolerance limits, yellow for wear exceeding these wear limits and red for critical wear values. In addition, these values can be shown as graphs with curves, showing wear curves in different colours on the interface. The colours of these curves can be selected and designated at will. Each curve represents individual sensor i.e. bearing that is monitored by that sensor.

Figure 2 – Curves showing operation of two selected sensors according to rpm (Source: AMOT Software Manual)

As shown in Figure 4, the yellow curve shows the number of engine rpm, while the other curves represent two sensors from cylinder No. 3. X axes on the graph represents the time period covered by the sensor readings. In this particular case in Figure 4, it covers six hours of engine operation and relevant sensor readings for this period. Furthermore, the software enables compilation of reports. Reports are the sum of all chosen parameters and they are stored in the computer along with the date of report. A special advantage is that these reports can be sent directly to the ship-owner, classification society, servicers, manufacturer and they can be seen on any computer on board if the crew member is an authorised user of the software. All the reports can also be shown on the interface at any time. There is also the possibility of showing multiple reports in order to compare data through a certain time period. In order to check and compare data from several reports, two or more reports can be downloaded and printed in column diagrams or graphs with curves to compare data from different reports. The interface will immediately be split in two parts with column diagrams or graphs with curves and enable comparison of data from reports. Moreover, the software has a special part called "Diagnostics". That is an interface showing operation of all parts of AMOT system as well as the possibility to monitor the sensors operation, their connections to the software, display in colours showing defects, malfunctions or failures of the same. Also, there is the possibility of display in colours during replacement of all or individual sensors, if necessary, along with the possibility of monitoring replacements or inspections of each individual component of AMOT system. During replacement of any component of the system or installation of additional equipment such as water in oil sump sensor, instruction manuals should be followed or manufacturer contacted directly. During replacement or first installation of the sensor on the engine, along with the mechanical arrangement the sensor calibration is required. Sensor calibration is done through software. After replacement in accordance with the instructions as shown in Figure 5, calibration in the software is necessary. If the sensor is properly installed and calibrated, it will be shown on the interface with all other sensors in green. If calibration is done on one of the sensors, that sensor will be shown in purple and it will not be shown in green until it is properly installed and calibrated.

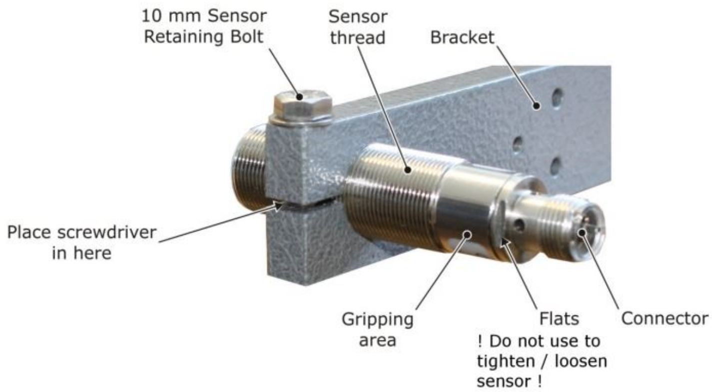


Figure 5 – Sensor and parts of the sensor if replacement or calibration is required (Source: AMOT Maintenance Manual)

During replacement of other components in the system, the software will show the component being replaced or disconnected from the system due to maintenance or survey in red colour until the component is safely returned to its place and connected to the system. After replacement of any sensor or component, the software will initiate 50-hour monitoring of the relevant sensor or component and show it on the main interface in the bottom. Also, if there is a defect or malfunction of the replaced sensor or component, alarm will be shown in that part of the interface in the form of a band glowing until a user confirms having seen the alarm or until the malfunction is corrected.

3. CRANKSHAFT DEFLECTION

Crankshaft is a fairly long and heavy part of marine engine that must withstand high stresses during explosion of mixture in cylinder as well as piston and connecting rod thrust during fuel and air mixture explosion. There are four types of crankshafts:

1. Solid forged crankshaft (made from a single piece) on MAN engines
2. Fully built crankshaft (webs and journal and crank pins are made from separate parts)
3. Semi built crankshaft (two webs are cast with the crank pin between them while the journal pins are fitted separately)
4. Fully welded crankshaft (all parts of the crankshaft are welded together)

Crankshaft is usually made from cast steel.

Crankshaft deflection mostly occurs in large marine engines. The deflection occurs after a certain period of running hours when the distance between crank webs is greater in top dead centre (TDC) or smaller in bottom dead centre (BDC). This deflection occurs eventually in all crankshafts, but it is rather negligible in smaller engines. The deflection is taken by measuring each crank for each piston respectively. Crankshaft deflection mostly occurs when the engine is running under excessive load (e.g. hogging and sagging of the ship when sailing on rough seas), increased temperature in the engine, excessive wear or improperly installed bearings, material fatigue (most commonly in crankshafts with bore for oil supply), insufficient lubrication, hydraulic thrust in the cylinder, vibrations due to slackening of bolts and cracks in the material. Since engineers are well aware of the problem, measurements are constantly taken.

3.1. Measurement of crankshaft deflection

Prior to taking crankshaft deflections, strict procedures should be followed:

- Since readings are compared with manufacturer's readings or previous readings, it is essential that deflections are taken under the same circumstances
- Engine main lubricating pump must be shut down
- Readings must not be taken while the ship is in dry-dock
- If any of the moving parts has been dismantled, the same should be mounted prior to taking crankshaft deflection
- Taking of deflections can be done only on calm sea, without wind
- Ship must be at zero trim
- Readings must not be taken during cargo loading or unloading operations
- Before using turning gear to rotate the engine for taking crankshaft deflection, indicator cocks must be open
- Ensure that all crankshaft bolts are properly tightened
- Crankshaft deflections must not be taken in tropical areas (because the sun is on one side of the ship causing deformation to ship's hull and structure, which will affect the readings)
- The sump must be ventilated prior entering

3.2. Measurement procedure

- Deflection gauge should be left in the machinery space so it can adjust to the temperature and engine surrounding
- Each crank web has a mark where the gauge should be set to provide correct readings (usually marked by the manufacturer)

- Crank webs should be cleaned - ensure that there are no oil residues prior setting the gauge
- If necessary, the gauge can be tied by a thin rope to prevent falling into the sump
- Turn the engine to bottom dead centre and set the gauge to "0". Record the readings under "just before bottom dead centre" (BDC1)
- Turn the engine 90° before top dead centre and record the readings under "STARBOARD" as shown in Figure 6.

Figure 6 - Crankshaft deflections on position starboard 90° (Source: https://mirmarine.net/stati-na-anglij skom/marine-engine/372-crankshaft)

- Next step is to turn top dead centre and record the readings under "TDC" as shown in Figure 7.

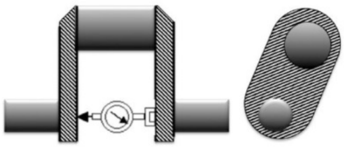


Figure 7 – Crankshaft deflection in TDC (Source: https://mirmarine.net/stati-na-anglijskom/marine-engine/372-crankshaft)

- Turn the engine for another 90° after top dead centre and record the readings under "PORT" (port side) as shown in Figure 8.

Figure 8 – Crankshaft deflection on position port 90° (Source: https://mirmarine.net/stati-na-anglijskom/marine-engine/372-crankshaft)

- Just before top dead centre record the readings under "just before top dead centre" (BDC2) as shown in Figure 9.

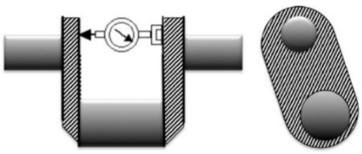


Figure 9 – Crankshaft deflection on position bottom dead centre (Source: https://mirmarine.net/stati-na-anglijskom/marine-engine/372-crankshaft)

The readings should be recorded in the Gauging Sheet. Readings "BDC1" and "BDC2" indicate vertical deflection, while "PORT" and "STARBOARD" readings indicate horizontal deflection of the crankshaft. After entering the data into computer, i.e. Gauging Sheet, the software will show deflection graph, together with graphs from previous or initial readings, which enables comparison of data (previous readings may show higher deflection due to flywheel operation).

3.3. Crankshaft deflection curve

In order to plot crankshaft deflection curve, it is necessary to draw a line parallel to crankshaft. After that, lines perpendicular to this parallel line are drawn for each bearing respectively. The readings obtained for respective bearings are recorded above each bearing. The next step is drawing deflection lines, again for respective bearings, starting from the first bearing towards the last one. Since in this example the initial value is -5.0 mm, the line will be drawn downwards (negative values are drawn downwards and positive values upwards) from the parallel line to obtain the line "ab" under an angle proportional to the deflection at point "a". This line is further extended to the perpendicular line of the next bearing. The next line is drawn in accordance with the measurement in the second bearing (in this case -2.0 mm), which is extended to the third bearing. The procedure is repeated for each bearing and relevant measurements are recorded. The following step is to draw a smooth curve ("deflection curve") along these connected lines. This curve is compared with the "base line" xy. Figure 10 shows deviation of the curve between bearings 1 and 2 which indicates that this section needs attention. This deflection measurement procedure is efficient and requires, besides taking readings and drawing, a lot of time. Consequently, software for drawing graphs and curves immediately upon entering recorded data is used nowadays. Deflection curve is obtained by transfer of data collected from one cylinder to the next. Positive values are shown by upward curve from cylinder to cylinder upwards, while negative values are drawn as downward curve. Figure 10 shows deflection line obtained by transfer in relation to the base line xy. By making comparison with respect to the base line, it is easy to determine which cylinders need inspection or more attention.

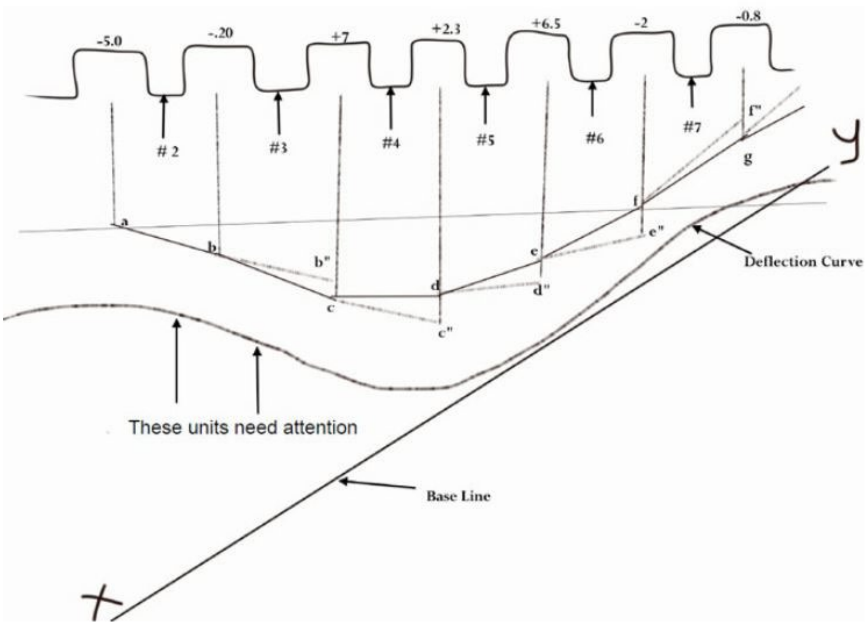


Figure 10 – Crankshaft curve obtained by transfer of data (Source: https://mirmarine.net/stati-na-anglijskom/marine-engine/372-crankshaft)

3.4. DI – 5C Crankshaft deflection measurement system

This system consists of hardware and software. It is used for taking crankshaft deflection. After taking deflection with system hardware, part of the hardware is connected to software which takes readings from micrometer and transfers them to the system software. The system automatically stores the data collected.

DEFLECTION DETECTOR DI-5C is connection between software and hardware for measuring, detection, recording and drawing graphs and deflection curves for marine main engines, auxiliary engines and generators. It consists of gauge dial in a case with cable outlet connected to data processor, shown in Figure 11. There are also extension bars for measurement of various crankshaft types taking into consideration the distance between webs. The second part of this system is software for recording and storing data on all engines on board. It also provides possibility to choose the engine on which we wish to take measurements at our discretion. Software can be installed on any computer on board because it does not depend on position or location of the computer and it is not connected to the dial or data processing unit.

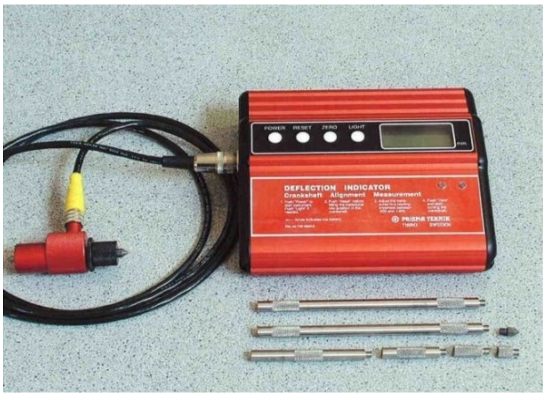


Figure 11 – Deflection gauge with extensions and unit for connection to computer (Source: Deflection Indicator Manual PC)

During installation of software the data processing unit should be connected to the computer and installation started. The computer will memorize the data processing unit for future communication and download of measurement data sent by the unit. When software installation is completed, it must be started and all relevant data inserted in order to enable proper operation of the software.

- SOFTWARE SET-UP

In order to set up software for taking crankshaft deflection, ship's data should be inserted first, which is done by clicking "CREATE" in the dropdown menu "FILE". Insert name of ship, purpose, tonnages and data on all engines on board. Number of cylinders, crankshaft measurements, as well as data from previous measurements should be inserted for each individual engine if the software was not initially installed by the manufacturer. After inserting data on each of the engines, software will create dropdown menu showing all the engines. By clicking on any of them, the engine chosen for crankshaft deflection measurement is selected. There is also the possibility to choose colours in which individual graphs or curve will be shown on the screen, which enables easier comparison with previous measurements or graphs or curves.

- DATA TRANSFER

All data recorded after taking measurements and stored via computer in data processing unit is saved onto computer hard disc in a chosen folder. Each measurement is saved under its designated number with the date. On the software main screen "head page" choose "load document" and a smaller screen will appear: "transfer screen". In the smaller screen choose a document from data processing unit according to the measurement date, depending on what data is required. Choose "transfer" and data is transferred from data processing unit onto computer, i.e. software screen.

This data will not be automatically saved onto computer, it has to be done manually through software.

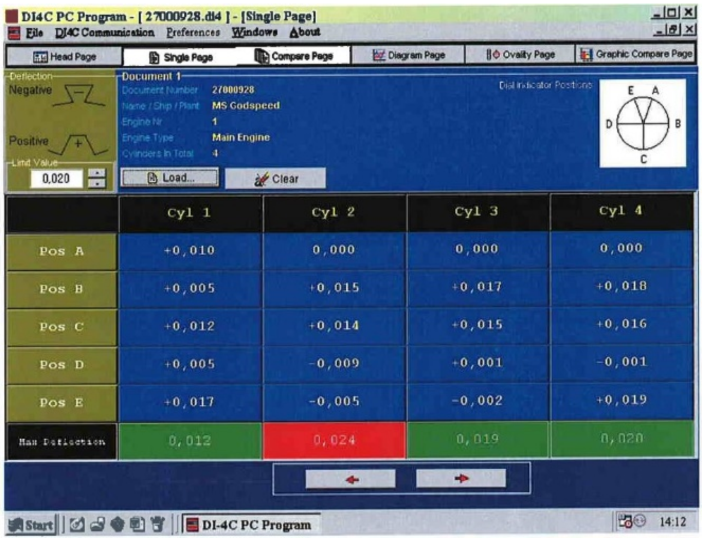


Figure 12 – Single page view (Source: Deflection Indicator Manual PC)

After taking measurements, software prints on the screen data for each cylinder and each position respectively, as shown in Figure 12. Deflections for each cylinder on each measured deflection are clearly and very neatly shown. If deflections are within maximum deflection tolerance values, maximum deflection will be shown in green (cylinders 1, 3 and 4), but if maximum deflection is above tolerance limit it will be shown in red (cylinder 2) alerting the user that crankshaft deflection on this cylinder requires attention or intervention. Furthermore, software provides possibility to compare data from previous measurements in numerical form or in curves. Thus, data from any measurement recorded can be compared with the new data. If option to compare recordings in the form of a curve is chosen, software will show a graph with curves of all previous measurements in different colours, showing the new measurement data in a chosen colour. This makes visual comparison of data easier as well.

Such graph is shown in Figure 13. Two recordings are shown as curves.

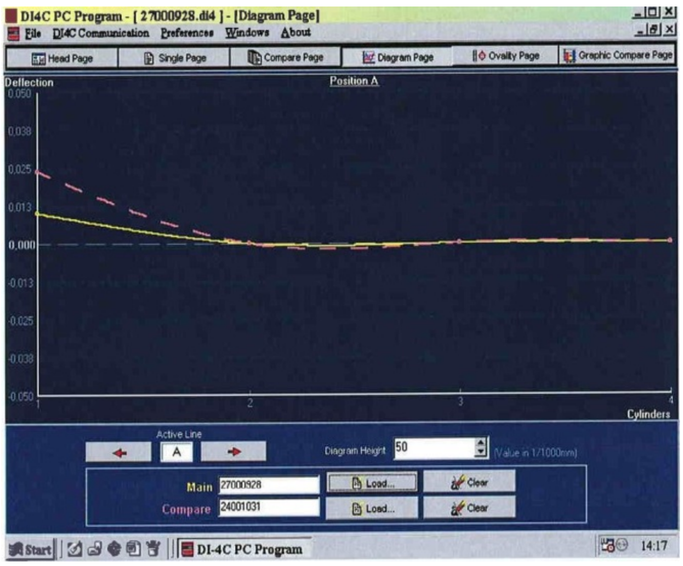


Figure 13 - Diagram screen (Source: Deflection Indicator Manual PC)

In addition, besides showing curves for chosen recordings, there is a possibility to show up to six measurement recordings regardless the time period or chronological order of data storage, to enable comparison of data. The screen will show deflection data in columns for six measurements in different colours. Figure 14 shows an example of this comparison of crankshaft deflection.

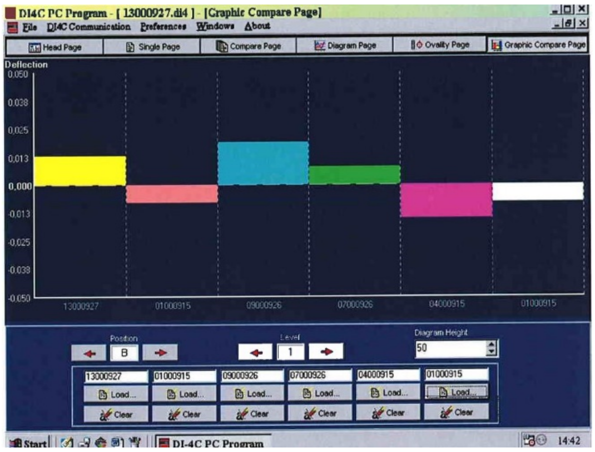


Figure 14 - Screen with graphic comparison of data (Source: Deflection Indicator Manual PC)

Along with the data shown on screen, measurement location can be chosen too (in the Figure, position B is chosen), which enables detection of deflection on a certain position and makes the choice of action easier in order to solve the problem at the exact position of deflection.

4. MEAUREMENTS AND TABLES

In order to test and analyse the above said systems, six measurements were taken and their graphs made in Microsoft Excel with horizontal and vertical deflections for each. Measurements were taken in the period from 2017 - 2021. Each of the six measurements was recorded in a table in which horizontal and vertical deflections were calculated according to formulae. Measurements were marked consecutively M1, M2, M3, M4, M5 and M6. Table 1 shows the position and prevailing conditions when the measurements were taken on board the m/v Ocean Shearer.

Table1 - Data on conditions and time periods when measurements were taken (Source: M/V Ocean Shearer)

	DATUM	TEMPERATURA KARTERA	RADNI SATI	MJESTO MJERENJA	TRIM
M1	30.05.2017.	48°C	698	Put za Shanghai	Fwd:-7,7 m Aft: -9.3 m
M2	02.09.2018.	40°C	16071	Yokohama	Fwd: 9.0 m Aft: 10.0 m
M3	02.04.2019.	39°C	20191	Hong Kong (na sidru)	Fwd: 9.05 m Aft: 9.5 m
M4	23.02.2020.	45°C	26250	Manzanillo	Fwd: 8.6 m Aft: 10.55 m
M5	25.01.2021.	45°C	31225	Hong Kong (na sidru)	Fwd: 5.2 m Aft: 5.8 m
M6	01.02.2021.	45°C	31356	Hong Kong (na sidru)	Fwd: 5.2 m Aft: 5.8 m

The obtained recordings for each individual measurement were entered manually into a separate table, horizontal and vertical deflections were calculated for each of the six measurements and deflection graph was drawn for each measurement. From these six tables, data on vertical and horizontal deflection was taken and new tables were drawn. One table represents all six vertical deflections calculated from the six measurements, and the other table represents horizontal deflection calculated from the six measurements of horizontal deflection.

4.1. Comparison of data

To compare data from all six measurements and calculations, all calculated data M1, M2, M3, M4, M5 and M6 must be summarized and entered in the table. Data should be separated into tables for horizontal calculations and tables for vertical calculations. After compilation of these two tables, graphs for horizontal tables and graphs for vertical tables should be drawn.

- VERTICAL DEFLECTION

Table 2 - Table of vertical deflection for the period 2017 - 2021 (Source: authors)

Br. Cilindra	1	2	3	4	5	6	7	8
M1	-4.875	-2.7	0.5	0.3	-0.5	-1.5	1.15	-7.5
M2	-4.75	-2.75	-1.5	-1.25	0	1.25	-2	-9.75
M3	-4.35	-2.6	-1	-2.5	0.25	1.2	-3	-7.6
M4	-6.75	1.75	-3.5	-1	0.15	0.55	-2.3	-5.75
M5	2.5	2.05	-2.5	-1.5	0.05	0.35	-2.25	-5
M6	2.7	1.5	-1.5	-2.5	0.25	1.4	-2.35	-4

Table 2 was drawn by entering all vertical deflections for each cylinder and their respective vertical deflection calculations. This table is to be used to compare vertical deflection data in the period from 2017 till 2021. From Table 2 and data shown, a graph of all vertical deflections in the period 2017-2021 is drawn. This graph is used for visual comparison of deflections taken in that period. The graph in Figure 15 indicates that curves M4, M5 and M6 show a slight downward trend in comparison to the previous measurements. However, deflection trends on bearings of the cylinders No. 2, 3, 4, 5, 6 and 7 are rather constant when comparing all six curves, while the end bearings, as indicated by curves, are more pronounced and show deviations.

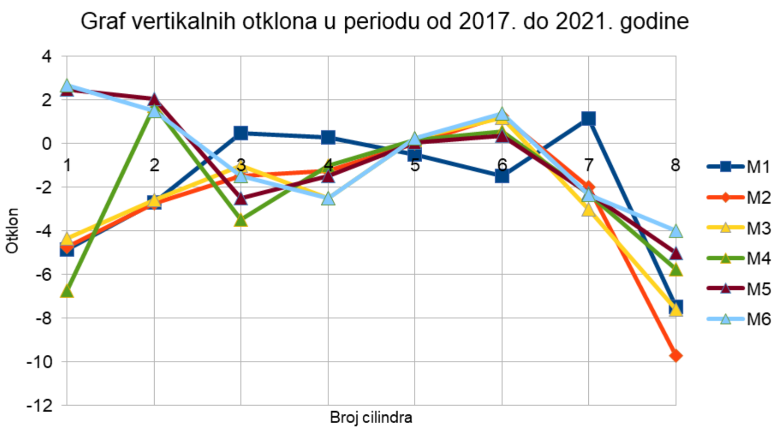


Figure 15 - Vertical deflection graph for the period 2017-2021 (Source: authors)

- HORIZONTAL DEFLECTION

Similar to the vertical deflections, the same procedure applies for horizontal deflections. Data obtained for each individual cylinder and each measurement is entered into a table (Table 3), showing that horizontal deflections are within limits, but there are still deviations on the first and the last bearing.

Table 3 - Horizontal deflection table for the period 2017-2021 (Source: authors)

Br. Cilindra	1	2	3	4	5	6	7	8
M1	-2	-1.4	-3	-2	-0.4	0.7	-2	-6.3
M2	0.5	0.5	0	1	-0.5	-0.5	-1.5	0
M3	-1	0.7	0.3	-1	0.4	-1.1	-2.5	-0.5
M4	0.5	1.8	-0.5	0	-0.5	1	-3.7	-1.5
M5	4.7	2.5	0.5	-1.5	-1.2	0.6	-3.2	-3
M6	4	2	1	-2	-2.6	1.5	-3.5	0.5

This data is used to draw a graph of horizontal deflections in the period 2017-2021 to enable visual comparison of horizontal deflections in this period. Graph 16 shows that data, similar to vertical deflection graph, for the cylinders No. 2, 3, 4, 5, 6 and 7 is constant and overlaps at some points.

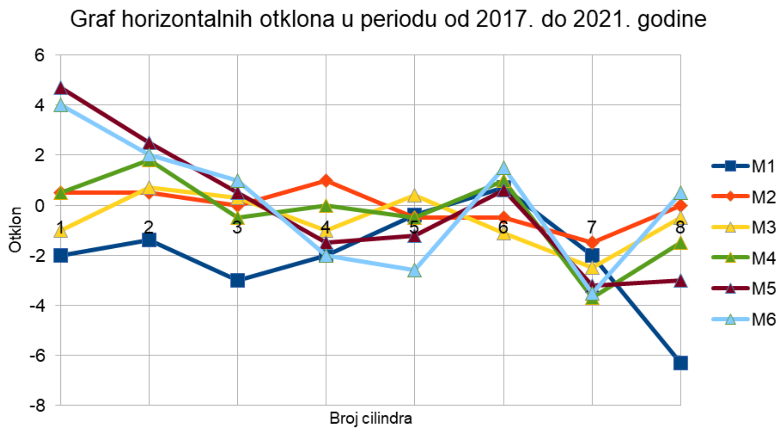


Figure 16 - Horizontal deflection graph for the period 2017-2021 (Source: authors)

Deviations on the end bearings are shown again, which indicates that close monitoring of the two bearings was justified and intervention is to be expected in the near future, or replacement of these two bearings if wear limit is exceeded or they are too damaged.

For proper comparison of data with deflection tolerance maximum values, it is necessary to find in the manual the page with maximum values of horizontal deflections for this type of MAN engine, Figure 17.

MAN Diesel

510-01.00 Edition 13	Checking of Main Bearings Alignment (Autolog)	Working Card Page 4 (7)

L21/31

Measurement of crank throw deflections by means of dial indicator (Autolog)		
Crank throw deflection	-	Difference in dial indicator readings in two diametrically opposite crank throw positions, i.e. two positions displaced 180°.
Vertical deflection	-	Difference in top-bottom readings.
Horizontal deflection	-	Difference in side-side readings.

Horizontal deflections of crank throws

Unless otherwise stated the values refer to cold engine.

For new or realigned aggregate	Aim for Acceptable	+ or – 3/100 mm + or – 5/100 mm
For aggregate in service realignment is recommended if deflections exceed		+ or – 8/100 mm

Figure 17 - Maximum values of horizontal deflection for MAN engine (Source: MAN User Manual)

After choosing values adequate for the type of engine for which calculations were made, maximum values are compared with all six recordings previously made. To make the comparison easier, Table 2 was compiled containing data on all six measurements and comparisons with absolute maximum values. As it can be seen from the data, all bearings are in good condition, except for the first and the last one, since they are usually connected to the flywheel, generator etc. which might be the reason for slightly increased, but still not alarming deflection values. Due to this fact, the end bearings are being closely monitored.

If we look closely at the data in Table 3 compiled from maximum deflections taken for each bearing (M1, M2, M3, M4, M5 and M6), it is obvious that none of the measurements recorded exceeds the maximum horizontal deflection limit. This confirms that crankshaft deflection of the relevant engine showed deflection values within limits during each measurement and no intervention or replacement of any of the engine bearings being measured is required. Only the end bearings are nearing the maximum deflection limit so they are being carefully monitored. If the values in future measurements and calculations continue to show this trend, those two bearings will be replaced with the new ones to avoid affecting other bearings (especially adjacent) in the engine, as well as deflection of crank webs.

MAN Diesel

Working Card Page 5 (7)	Checking of Main Bearings Alignment (Autolog)	510-01.00 Edition 13

L21/31

Vertical deflection of crank throw nearest flywheel Unless otherwise stated the values refer to cold engine.	
Flexible coupling between diesel engine and driven machine	
- New or recently overhauled engine, nominal	+ 8/100 - – 24/100 mm
- New or recently overhauled engine, max.	+ 15/100 - – 27/100 mm
- Operating engine, check alignment immediately	+ 22/100 - – 30/100 mm
Flexdisc between diesel engine and driven machine	
- New or recently overhauled engine, nominal	+ 8/100 - – 28/100 mm
- New or recently overhauled engine, max.	+ 15/100 - – 35/100 mm

Vertical deflection of crank throws remaining Unless otherwise stated the values refer to cold engine.	
Rigid and flexible coupling between diesel engine and driven machine	
- New or recently overhauled engine, nominal	+ or – 8/100 mm
- New or recently overhauled engine, max.	+ or – 15/100 mm
- Operating engine, check alignment immediately	+ or – 22/100 mm
Flexdisc between diesel engine and driven machine	
- New or recently overhauled engine, nominal	+ or – 8/100 mm
- New or recently overhauled engine, max.	+ or – 15/100 mm
- Operating engine, check alignment immediately	+ or – 22/100 mm

08028-00/H5250/94.08.12

05.02 - ES0

Figure 18 - Maximum vertical deflection values for MAN engine (Source: MAN User Manual)

When comparing the data obtained by measurement and calculations (M1, M2, M3, M4, M5 and M6) with maximum deflections shown in Figure 18 for MAN engine no deviations from normal deflection values or vertical deflection maximum limits were observed. Similar to the horizontal deflection, slightly increased values were recorded for the end bearings only, indicating there might be a minor damage to these. Both bearings were under constant monitoring.

5. CONCLUSION

AMOT system is one of the many systems used in modern navigation for monitoring, measuring and alerting in case of malfunction. In this paper we proved that connection of surveillance and maintenance system is a valuable and useful arrangement for detecting eventual faults, prevention, repair and maintenance of crankshaft and crankshaft bearings. AMOT system provides precise and readily available measurement results, sensor status and wear of bearings in different colours. Since installation, maintenance and software operation of the system is simple, it is being more frequently applied in practice and installed on modern ships. In order to update and extend the possibilities of monitoring additional parts of the engine, there is an option to install additional sensors and parts to be monitored.

Programme system for crankshaft deflection measurement DEFLECTION INDICATOR DI – 5C is a useful and functional system for taking crankshaft deflections and the management and processing of data obtained through measurements. Its operation, in the combination with AMOT system, forms a unit that is more than sufficient for every marine engineer as it is making their job easier, saving time and obtaining more precise data on measurements and calculations.

As elaborated in the paper, synergistic operation of the two systems was tested by collecting data through AMOT system. Further deflection measurements were taken by DI – 5C system. Data collected was inserted into Excel tables and relevant calculations and graphs made for all measurements. Further analysis and comparison of data collected showed that performance of both systems excelled and there were no errors, which confirms the systems are fully operational and fulfil their purpose.

This research has shown once again that technological advancements in co-operation with classical methods for taking measurements and calculations bring results. It has also shown that technology is a valuable tool in detecting malfunctions in operation, breakdowns or failures of individual engine parts, as well as in taking crankshaft deflections, dealing with issues in engine operation in record time. The reporting and data storage system of the both systems ensure smooth communication and presentation of data to manufacturers, servicers, classification societies and ship-owners. This communication provides engineers with better co-operation opportunities with manufacturers and servicers on shore when deciding on actions to be taken, choosing and ordering spare parts, getting approvals from ship-owners for purchasing spares. since information on condition of individual part of machinery, for which the systems indicates malfunctions or failures in operation, is readily available to everyone involved. Moreover, the repair process is much faster, which reduces detentions/demurrage and also significantly reduces costs of repair.

REFERENCES AND WEB SOURCES

[1] AMOT System Overview
[2] AMOT Maintenance Manual
[3] AMOT Software Manual
[4] https://mirmarine.net/stati-na-anglijskom/marine-engine/372-crankshaft
[5] Deflection Indicator Manual PC DI – 5C
[6] M/B Ocean Shearer
[7] MAN Diesel Manual (M/B Ocean Shearer)
[8] Calculations and tables made in Microsoft Excel as part of the master's thesis
[9] MAN User Manual

SOLUTIONS OF CNG AND LNG SUPPLY SYSTEMS IN MODERN LAND AND MARINE CI ENGINES WORKING IN DUAL-FUEL (NG – DIESEL) MODE[1]

Mirosław Karczewski
Institution: Military University of Technology in Warsaw
Warsaw, Poland
E-mail: miroslaw.karczewski@wat.edu.pl

Grzegorz Szamrej
Institution: Military University of Technology in Warsaw
Warsaw, Poland
E-mail: grzegorz.szamrej@wat.edu.pl

Janusz Chojnowski
Institution: Military University of Technology in Warsaw
Warsaw, Poland
E-mail: janusz.chojnowski@wat.edu.pl

UDK 629.5:621.43
665.6

Summary

In modern world, due to exhaust emissions restrictions in all economy sectors, alternative fuels might be the fundamental element of further development of internal combustion engines. Natural gas as a fuel for internal combustion engines allows to meet expectation of incoming requirements of exhaust gas emission standards. These standards would highly limit usage of internal combustion engines working on conventional fuels. The method of supplying gaseous fuel to the engine combustion chamber determines the effectiveness of the applied solution and the efficiency of fuels energy conversion. A compression ignition internal combustion engine is a type of reciprocating piston engine that results in the highest efficiency in converting the chemical energy contained in the fuel into mechanical work. The use of Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) as the only engine fuel does not allow the Compression Ignition (CI) of the air-fuel mixture. It becomes necessary to use other fuel, which initiates the autoignition of the air-fuel mixture. The aim of this study is to indicate modern solutions for supplying dual-fuel engines with natural gas (in the form of LNG or CNG), which enable compliance with the latest exhaust emission standards for piston engines. Fuels like LNG and CNG are useful in many modern engines applications such as: ships, cars, trucks, trains, factories, generators, power plants and working machines. This study will outline the solutions used in all of these applications.

Keywords: dual-fuel, RCCI, CNG, LNG, engine supply systems.

1. INTRODUCTION

Solutions shown in this paper are used in combustion engines fuel supply systems working in dual-fuel mode. Most of these types of systems are based on already existing solutions, but their common application requires changes and reflections on their assembly and purpose. All the solutions presented in the article are

[1] The publication was created as a result of work under: Poland Republic, National Centre for Research and Development, Military University Technology; Name of the competition: Ścieżka dla Mazowsza; Agreement No. MAZOWSZE / 0123 / 19-00; Subject: "Innovative ecological CNG installation for diesel engines limiting the emission of harmful exhaust components together with a mobile diagnostic platform."

used in Internal Combustion (IC) engines of various sizes, speed and applications. These solutions vary depending on the application of the engine and its size. All cars solutions are much more simply than those which are used in marine engines, applied on land and at sea, where power generated by the engine is bigger than in a land vehicle, and access to natural gas is better. Such engines are used in ships but also in big manufactories and power plants, generating electricity and/or useful heat. The scope of their application depends only on the human level of energy demand in the chosen place or region and the availability of two compliant fuels, which can be used in that kind of engine.

1.1. The basics of dual-fuel engine working mode

Engines working on two fuels simultaneously can be named in a few acronyms, but the most promising for future use is the Reactivity Controlled Compression Ignition (RCCI) engine. RCCI is an engine type where ignition method based on small amount of high reactive fuel use in combustion chamber full-filled with low-reactive fuel. The high reactivity fuel can be a diesel fuel, and low reactivity fuel (high octane fuel) is usually the gaseous fuel [1]. In research studies there was a lot of fuels used in this type of engine - basic requirement is a high octane number. Basically in the process of developing this type of ignition fuels such as gasoline, Natural Gas (NG), Liquefied Petroleum Gas (LPG) or alcohol and high octane biofuels. The injection of diesel fuel fundamentally based on proven technologies used in classical Compression Ignition (CI) engines. Apart from diesel fuel, in RCCI engines could be used every fuel whose properties are similar to those of diesel fuel and ensure its immediate self-ignition. Commonly it can be a diesel type biofuel like Fatty Acid Methyl Esters (FAME) or Fatty Acid Ethyl Esters (FAEE), Rapeseed Methyl Ester (RME), soyabean methyl ester (SME), Jatropha Oil or even hydrotreated vegetable oil (HVO) which is a highly converted biofuel. The choice of fuels used depends primarily on the engine concept, so the problem of a given fuel supply system is a very important point in RCCI engines solutions. RCCI engines are able to use any fuel known for engine applications, whose reactivity level (octane number) is enough high or enough low to accept their usage. This paper will present all the dual-fuel systems used in engines of various sizes and uses of which the highest known form are RCCI engines which in a very promising way increase thermal engine efficiency and reduce the emission of those harmful exhaust components whose are difficult to eliminate in classical CI diesel engines, like NO_X, CO_2, PM and SO_X - in the maritime applications. Using these types of engines together with well-chosen fuel supply systems can take piston engine greenhouse gas emissions to a whole new level.

2. FUEL SUPPLY SYSTEMS FOR DUAL-FUEL ENGINES

Fuel supply systems in dual-fuel engines are based on proven solutions from other piston engine types. The most common used in dual-fuel fuel supply systems are based on diesel engine injection system and gas fuel supply system commonly used in Spark Ignition (SI) engines. Fuel supply systems for dual-fuel engines can be divided into several chapters, starting with the oldest and simplest basic systems, and ending with those that seem to be the most advanced and efficient today.

2.1. Basic fuel supplying in dual-fuel engines

For small, medium speed engines used in cars and small power generators dual-fuel supply systems are quite popular and well known. The most common used supply system is indirect injection of high octane fuel and direct injection of high reactivity fuel. In unscientific use, the high octane fuel is always a gaseous fuel, like CNG, evaporated LPG or evaporated LNG. The most popular point for gaseous fuel injection is the intake manifold, or intake system pipe in the older technologies - where the gas mixer is placed. A sample look of gas mixers or its throats - used in marine engines on ships or energy plants, and small engines applied in cars or boats are shown in figure 1.

Figure 1 The examples of throat constructions from gas mixers for different engines.

Source: [2]

Gas mixers from figure 1 shows the throats and all gas mixers. Gaseous fuel is supplied via bores in the housing and via bores in the tube in the middle, which is known as a bar [2]. This way of supplying fuel to the engine through its intake system is essentially the oldest type and bars shown in the figure 1 represent the most primal way of fuel supplying. In present IC engine technology only gaseous fuels are supplying in this way. Those kind of technology is commonly use in gas engines in all sizes. Their widespread use is due to their simplicity and low maintenance costs. The principle of operation of such a device and its cross-section are shown in the next figure, figure number 2.

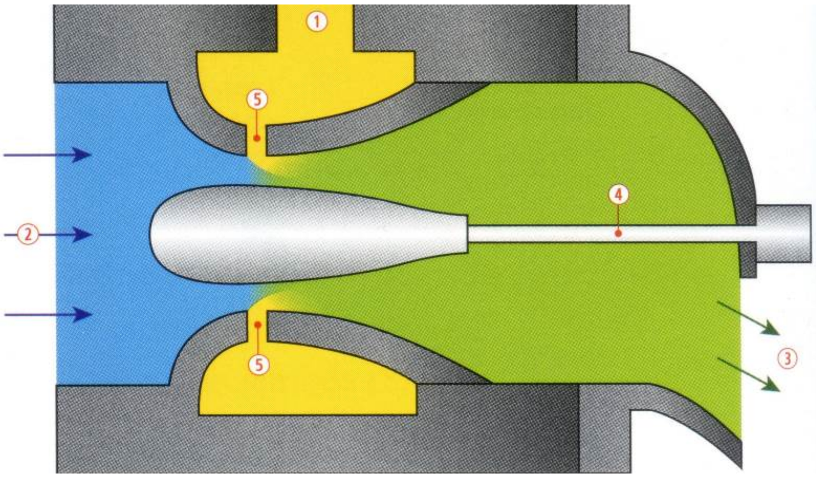


Figure 2 A cross-sectional view of a gas mixer with an adjustable venturi insert,

Source: [3]

Figure legend:
1 – the gaseous fuel supply,
2 – air supply,
3 – the air-fuel mixture to the intake manifold of the gas- or dual-fuel engine,
4 – the adjustable venturi insert shaft connected to stepper motor,
5 – bores for the supply of fuel-gas in the throat of the gas mixer.

Operation of the simple gas mixer is similar to the basic carburetor, where a venturi is used to suck fuel by the air flowing through it. This type of dual-fuel injection is the first and the simplest type of fuel supply. A development of this fuel delivery method is the introduction of fuel injection in the intake manifold. The point of fuel delivery should be as close to the intake valves as it is possible, because of the time required for the fuel to flow from the injection point to the combustion chamber and the inertia of the entire system. In this system the pressure of the fuel is not so important as in another, because of Venturi effect. In large-scale engines this way of fuel supplying is not the simplest way to deliver the gaseous fuel into the intake manifold.

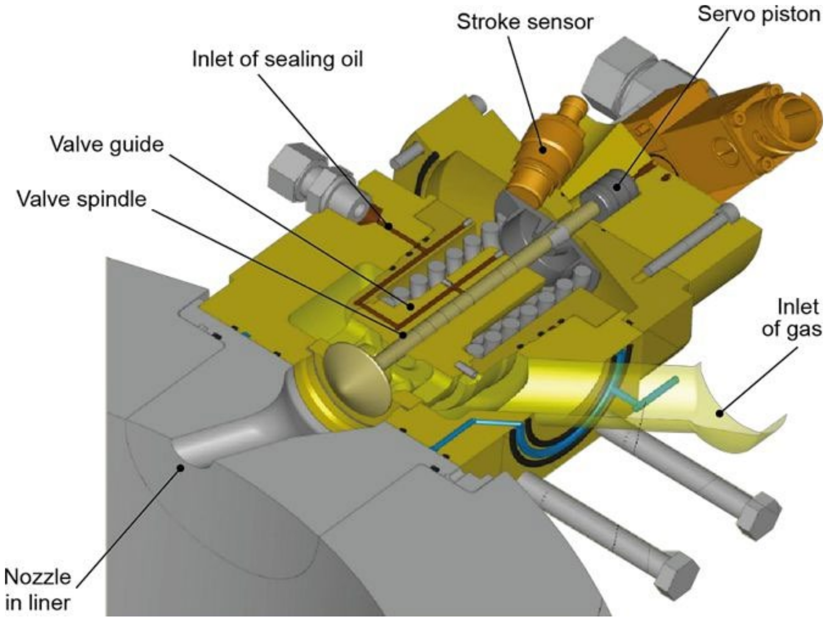


Figure 3 CAD drawing of the valve-controlled gaseous fuel direct supply.

Source: [4]

The simplest way of gaseous fuel delivery is through the valve. Valve can be placed in the intake manifold or in the structure attached to the engine cylinder head. Pressure of the gaseous fuel is sufficient for creating the enough amount of fuel flow through the valve, when it is opened. The most common kind of this solution supplies fuel into the intake manifold, but in the figure 3 more advanced application of that is showed.

2.2. Injection of both fuels in dual-fuel engines

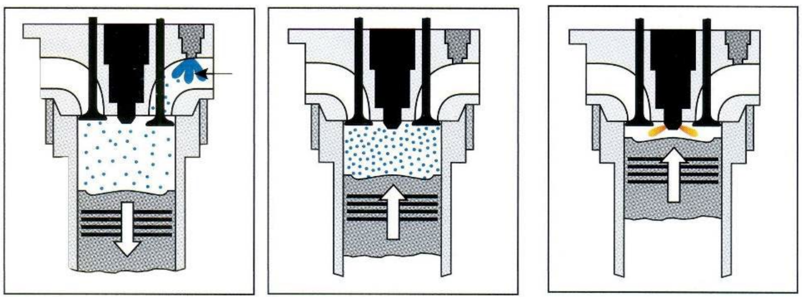


Figure 4 Schematic drawing of simply dual-fuel injection engine work.

Source: [3]

Schematic show of classic described in this paper dual-fuel injection system of both used fuels is shown on figure 4. The way of low reactivity fuel supply can be improved by using a fuel injector in a place of gas mixer. When there is a necessity of using liquid low reactivity fuel, the fuel injection may be indispensable. The indirect injection of fuel can be placed anywhere in the intake manifold, but the best quality of fuel supply can be achieved by placing the injector as close to the inlet valves as possible. The long way to go for fuel with air gives the opportunity to create a well-mixed air-fuel mixture, but to long way creates a mismatch in the injection time to the fuel demand of the engine. There could be also a problem of the flow of already injected fuel by the turbo charger, what is undesirable and potentially dangerous. So the best solution is to locate the injector directly in front of the intake valve. This type of dual-fuel supply system is a classic way of fuel delivery too, but more technically advanced due to the use of more expensive than carburettors fuel injectors.

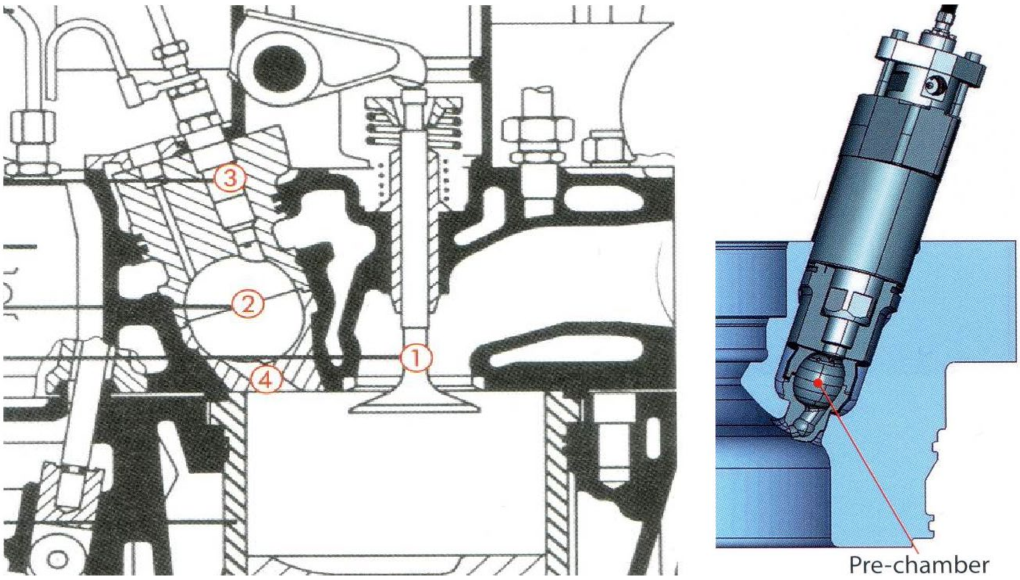


Figure 5 A Ricardo pre-chamber in a conventional four-stroke medium-speed diesel engine on the left and the full pre-chamber draw with the indication of main pre-chamber on the right.

Source: [2], [3]

Figure legend:
1 – exhaust valve,
2 – pre-chamber,
3 – pintle- type injector,
4 – tangential channel.

In bigger gas engines, used in maritime, where bores are larger than 200mm, a pre-chamber is used, so solutions describe above are not enough to make a correctly fuel supply [3]. The view of the modern pre-chamber drawing is shown in the figure 5 on the right, in comparison to primary kind of pre-chamber shown in the same figure on the left.

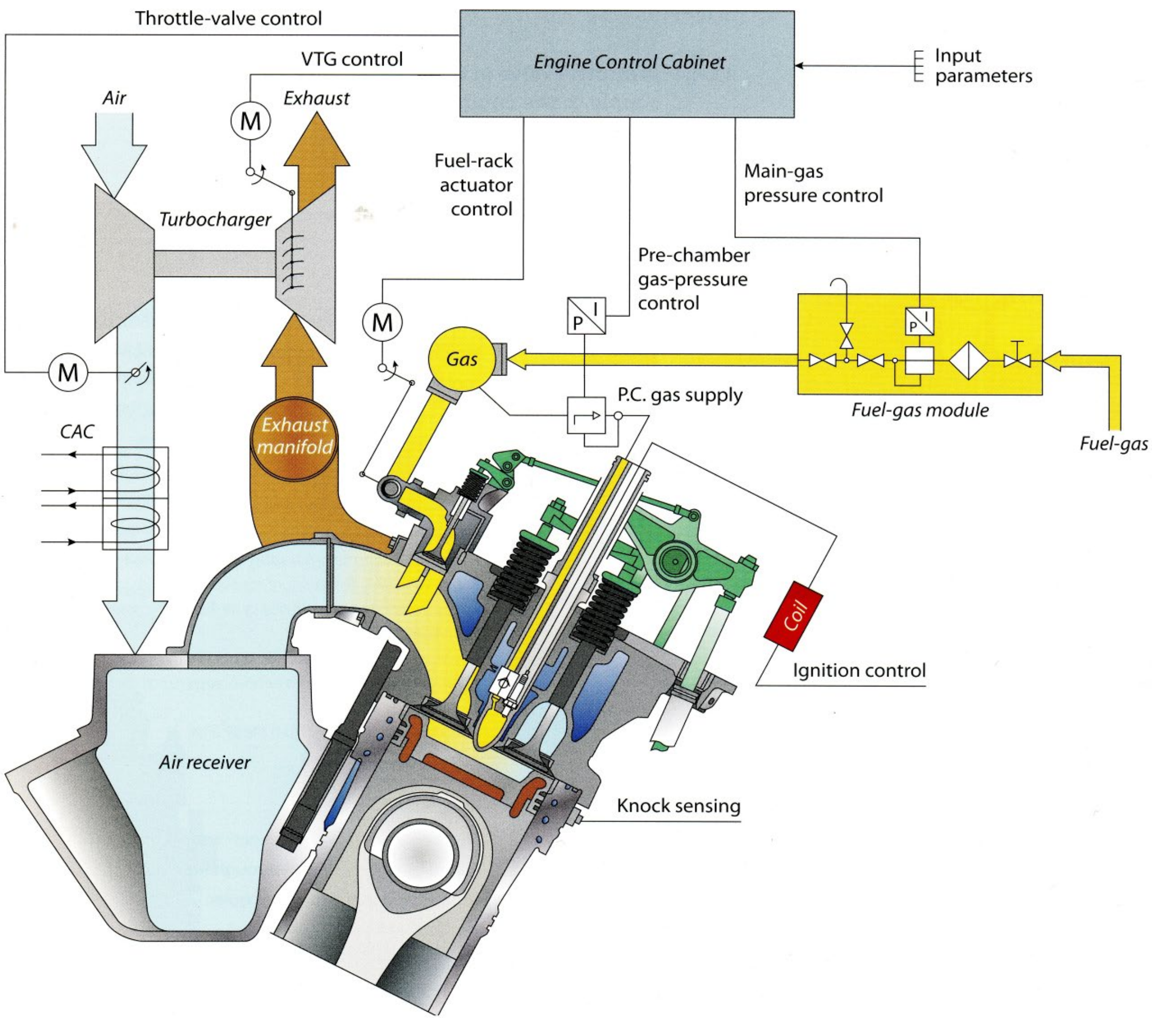


Figure 6 An overview of the gas supply for Rolls-Royce turbocharger gas engine - the gas supply principle for the Rolls-Royce gas engine showed on the cross-section drawing.

Source: [3]

Those kind of pre-chamber is still used in a conventional CI engine. The very similar kind of pre-chamber was used in CI engines from the beginning of the existence of CI engines. Pre-chamber can be easily fuelled by diesel fuel, but the high octane fuel supply into pre-chamber is not so easy to performance. To supply in this pre-chamber two types of fuels in marine engines there are used two points of fuel supply (usually both of them are being released by injection). In the figure 6 it is possible to see all schematic mode of action for this hybrid type of fuel supply in the Royce-Rolls engine.

Figure 6 shows the direct injection of gaseous fuel into the pre-chamber and the gas supply valve which is responsible for fuel release into the intake manifold, as it was described in the previous subchapter. The way of gaseous fuel supply injector or valve steering to replace with operation could be electric or fully mechanic. In maritime engines, mechanically operated valves are common, because the factor causing the gas to enter the intake manifold is its pressure. Every gaseous fuel is stored under pressure. Rolls-Royce engine from figure 6 is called Lean-Burn Gas Engine, where engine operates according to the Otto Cycle [5].

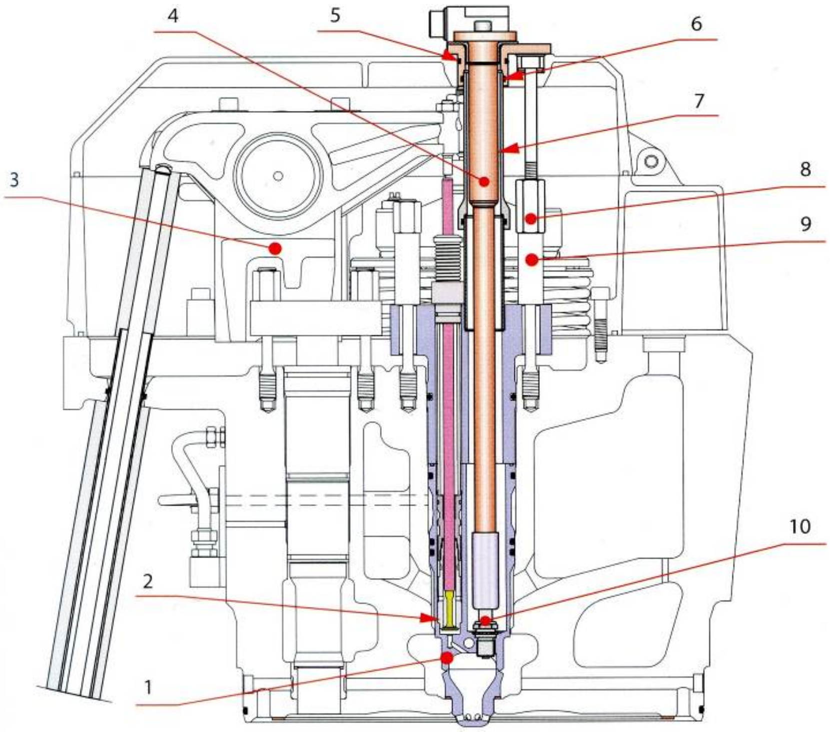


Figure 7 The pre-chamber, installed in the cylinder head of a Wärtsilä gas engine, type W34SG.

Source: [3]

Figure legend:
1 – pre-chamber,
2 – pre-chamber valve,
3 – rocker arm bracket for the pre-chamber fuel-gas valve,
4 – ignition coil,
5 – O-ring,
6 – O-ring,
7 – sealing sleeve,
8 – a nut,
9 – sleeve,
10 – spark plug.

In the figure 7, the fuel supply system for dual-fuel engine with pre-chamber is shown in the greater zoom. On those two picture we can see the spark plug which is responsible to start the ignition of air-fuel mixture. This types of engines are not a dual-fuel engine, but the idea of using the pre-chamber, and direct fuel injection in dual-fuel engines are used in the next type of fuel supply for them, described in next part of article. The location of the injector in the place of the spark plug is not a technical problem - as was described – the first pre-chambers in CI engines were equipped with a diesel injection system.

Such a type of gaseous fuel injection and its system of work is shown in the next figure number 8, presenting a schematic operation processes of single-fuel gaseous engines. This kind of engine fuel supply is described because of its importance in the further development of engines using gaseous fuel in dual-fuel mode. In the most maritime engines, their manufactures would not develop dual-fuel engines without using described here gaseous engines with the pre-chamber.

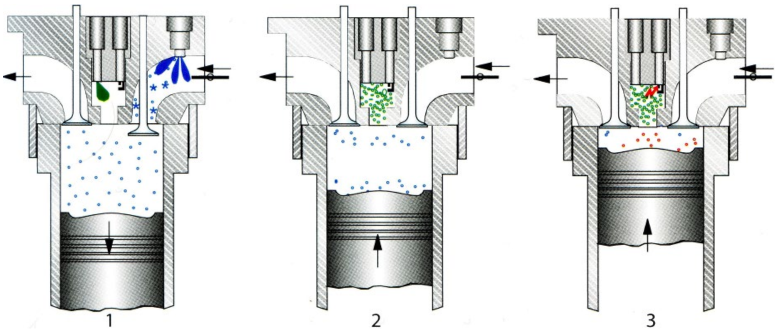


Figure 8 Operations of gaseous fuel maritime of Wartsila 20V34SG, gas engine principle.

Source: [3]

There is possibility to use two different high octane fuels where blue colour is responsible for gaseous fuel, and green colour is responsible for liquid high octane fuel like gasoline. Numbers shows the sequence of engine operations like in the figure legend.

Figure legend:
1 – fuel injection,
2 – air-fuel mixture forming,
3 – spark ignition of rich air-fuel mixture in pre-chamber.

Figure 8 present the mere use of two different types of injectors (or direct injector and indirect supply of gaseous fuel) makes possibility for use more than one fuel for combustion. Those type of dual-fuel engine, where another than gaseous fuel with high octane ratio is used is shown in the figure 8, where for example gasoline fuel may be used in direct injection into the pre-chamber. This is possible thanks to the use of more than one fuel injector, but the essence of this method - with pre-chamber usage - is the possibility to use two high-octane fuels like CNG, LPG or gasoline. In that conception, even NG in different physical properties could be used, for example to supply pre-chamber. This solution introduced the possibility of using two fuels in dual-fuel engine to a new level, but changing the technical solutions allowing the use of two fuels remained a technical conundrum for designers. One of the key problems was trying to fit two injectors into the combustion chamber.

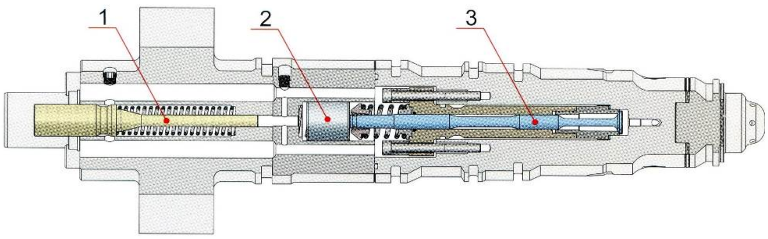


Figure 9 The mechanical-driven valve for the fuel gas to the engine pre-chamber.

Source: [5]

Figure legend:
1 – hydraulic plunger for oil pressure,
2 – hydraulic piston opens gas valve needle 3,
3 – guide for gas valve needle.

Production of a gas fuel injectors are problematic for reasons of physicochemical properties of gaseous fuel. Its dimensions are bigger than diesel injectors, materials from which it is made are different and the method of control, and thus the technology of its implementation, is also a bit different. Mechanical-driven injectors are a bit bigger than modern electronically controlled injectors. The structure of such an exemplary mechanical injector is shown in Figure 9. Figure 9 shows the mechanical-driven valve in the gas fuel injector. Important things are engine and injectors – what is related to it – dimensions of the pre-chamber. Fit both of these devices in one cylinder is important, and impossible in smaller units. Even in maritime such a combination is not common and the difficulty of applying them together forced further development of direct fuel supply systems for dual-fuel engines.

Figure 10 A complete pre-chamber that will be installed in the centre of cylinder head.

Source: [2]

In small engines, pre-chamber is not big enough to fit two injectors into it. Even only the gaseous fuel injector could be too large for that application. In bigger engines pre-chamber and secondary fuel injector is not enough tight to apply both of them in the engine cylinder. In large marine engines pre-chamber could be big enough for that – in the figure 10 the photo of the pre-chamber mounted in the engine cylinder head is showed.

Gaseous fuel injectors are bigger than injectors intended for liquid fuels. Gas injectors intended for injecting fuel to pre-chamber could be possible only in large scale combustion engines.

Next chapter shows the techniques used for direct injection of gaseous fuel into the combustion chamber.

2.3. Direct injection of both fuels in dual-fuel engines

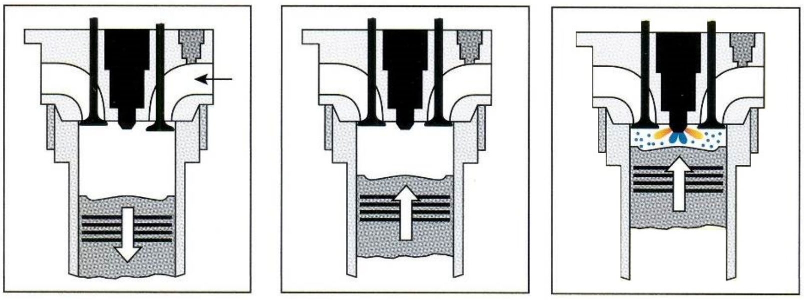


Figure 11 Schematic drawing of direct dual-fuel injection engine work.

Source: [3]

The last type of fuel supply for dual-fuel engine is direct injection of both fuels into the engine combustion chamber. That strategy could be realized by a few technologies, based on the both fuel injection process.

First is realized by use two or more independent injectors. Second idea is to use one injector for two or more types of fuel or substances – which was successfully realized by a few manufacturers. Those strategies are schematically shown in the figure 11.

This kind of fuel supplying in RCCI engine have got another name which is Direct dual-fuel Stratification (DDFS). Switching to this type of fuel system enables multiple injection of both or one of the fuels directly into the combustion chamber, depending on the needs of the engine developer or his researcher, and the appropriate adjustment of the fuel injection timing is a matter of engine fuelling strategy. Basically those dual-fuel engines have got simply fuel supply strategy, where the gas and a pilot fuel is injecting in a similar moment in time. It can be more than one pilot injection of diesel fuel, and different time of injection of fuels, but in standard dual-fuel or RCCI engines with direct injections system, both fuels are injecting near the end of the compression stroke. In all types of RCCI engines problematic is the angle of injection and its shape.

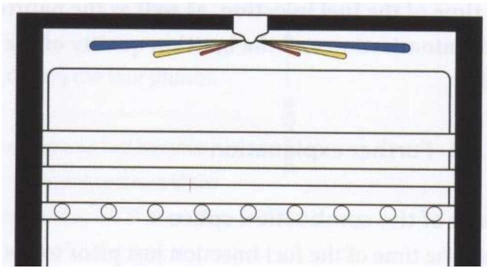


Figure 12 Shown of the fuel injection process with various fuel-injection possibilities in example of different angles of injection.

Source: [3]

In RCCI engine the injector angle must be different than in classic CI engine. Normal diesel fuel injector is placed near the centre of the top of combustion chamber and its spray angles are limited by its position and construction. Figure 12 shows the possible spraying angles for classical fuel injector and options to change them. Geometry of combustion chamber in RCCI engine is not similar to that known from classic CI diesel engine and it requires completely different shape of injection. Even the amount of high reactive fuel injection is smaller than in single fuel engine, the points where this fuel must be delivered is fundamentally different.

Figure 13 Correct injection spray shapes in the injection flow of a four-stroke trunk-piston engine (left), in a large two-stroke crosshead engine with three injectors (centre), and a two-stroke crosshead engine (right).

Source: [3]

Low reactive fuel mixed homogenously with air in RCCI engine must be located everywhere in the space of combustion chamber, so injected high reactive fuel must initiate ignition in all of those homogenous structure at the same time. Classical in CI diesel engines combustion chamber is located inside the piston, where all fuel is injected and burned. Figure 13 shows the correct positioning of the air-fuel mixture in the combustion chamber. From injectors construction depends the correctness of arising the air-fuel mixture and its arrangement in the combustion chamber. Combustion gases leave the combustion chamber space after burning and they spread over the entire space of the cylinder. In dual-fuel engine, those burning process takes place in the entire over the piston cylinder head space. The shape of piston in good designed RCCI engine is closer to the known one in such an SI engine. For this reasons, the high reactive fuel injector must be different in those type of engines.

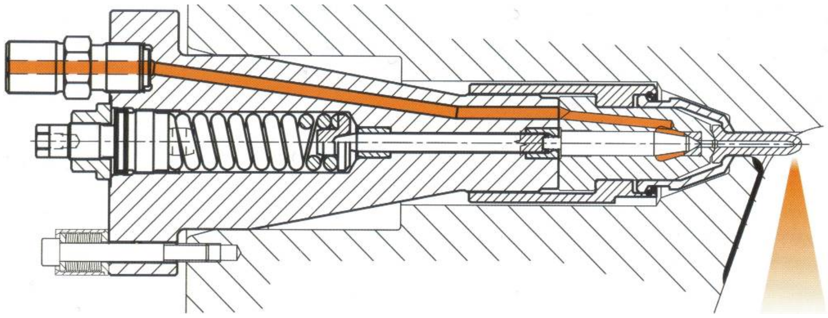


Figure 14 The position of the injector at the edge of the combustion chamber in a two-stroke crosshead diesel engine

Source: [3]

In addition to using an injector located centrally in the cylinder head, in many maritime engines injectors are located in different places of the cylinder head or such a cylinder. In marine two-stroke engines problem of different injection shape is solved by cylinder head injectors with a spray injecting at right angle or injectors placed in the middle of the cylinder – not in the cylinder head. In the figure 14 the drawn of the special right-angle spray injector is showed.

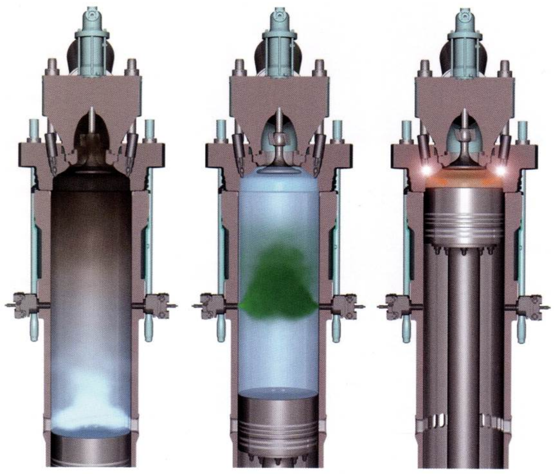


Figure 15 Fuel injection process in two-stroke maritime engines, where the principle for the injection of low pressure gas through the cylinder liner during the upwards movement of the piston is clearly visible.

Source: [3]

Figure 15 shows the injection system in two stroke marine engine, where gaseous fuel is injecting direct into the cylinder when the piston starts to move upwards to its top position. Injected gas has got much time to create air-fuel mixture, and at the top piston position secondary high reactivity fuel is injecting, starting the combustion process. The same effect can be achieved by spark plugs, but it would not be a dual-fuel engine, as defined in that article. Those solution is known only from a large-scale two-stroke maritime engines.

In many ways this solution is great, but prevents the implementation of more advanced fuel injection strategies based on multiple injections of low reactive fuel at the end of the compression stroke, when the piston is already above the fuel injection line. Of course, apart from that, the use of this technique is possible only in two-stroke dual-fuel engines and their occurrence is limited only to the large-size engines, applied in stationary use or in maritime use.

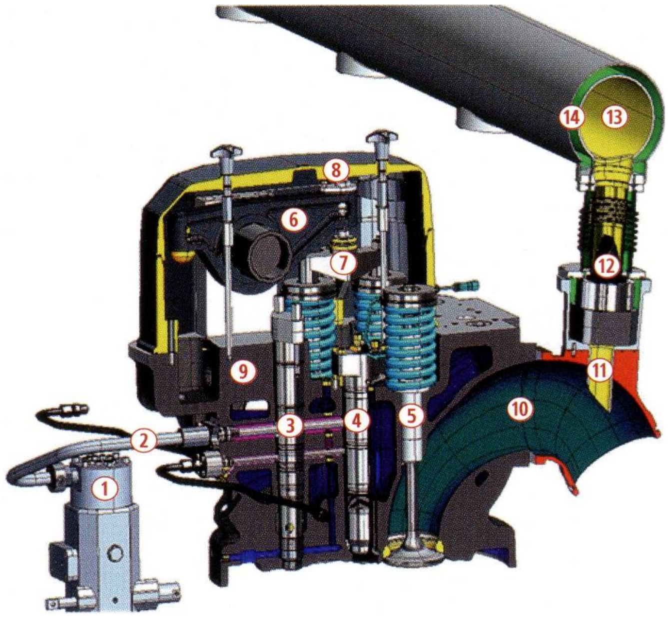


Figure 16 The fuel-gas-air mixture supply in Wartsila dual-fuel engines, where:

Source: [3]

Figure legend:
1 – high-pressure fuel pump,
2 – high pressure fuel supply pipe, double wall design,
3 – pilot liquid-fuel-injection nozzle,
4 – main-liquid fuel fuel-injection nozzle,
5 – one of two inlet valves,
6 – rocker arm of both the intake- and inlet-valves drive,
7 – yoke for the drive of both intake valves,
8 – valve cover,
9 – cylinder head,
10 – air-intake manifold,
11 – fuel-gas supply in intake manifold,
12 – solenoid valve for the fuel-gas supply,
13 – main-fuel gas supply-pipe,
14 – space between inner- and outer wall. In this space, where a lower pressure relative to the engine space is found in order to prevent fuel-gas leakages to surrounding areas.

One of the more technically advanced options for delivering both fuels to the engine's combustion chamber is usage of two independent injectors located in the engine cylinder head. In four stroke engines such a solution is much more popular than use one dual-fuel injector because of its construction complexity. Figure 16 shows the cross-section of cylinder head of Wartsila engine, where different numbers represent the different parts of the fuel supply system. On the left side of this figure we can see liquid-fuel pilot injection in the cylinder head for the ignition of the compressed fuel gas/air mixture. On right side there is the intake duct or manifold with the fuel-gas supply via the electronically-actuated and operated solenoid valves [3]. That is the development of the simply valve-supply concept of gaseous fuel supply. In that engine cylinder head sufficient space for two injectors has been found. But the functionality of those injectors corresponds to two working modes for this engine – dual-fuel working mode, and single fuel work, where only a diesel fuel is injecting. Those bigger injector, marked in the figure 16 by number 4 is responsible for the possibility of engine work only with a diesel fuel. Usage of two high reactive fuel injectors per one cylinder also response for a very high demand for high reactive fuel in a bigger engine loads. The occurrence of such a phenomenon results from the fact, that high reactivity fuel is usually much more caloric, because its energy value is higher than those of low reactivity fuel. The necessity to use such a solution shows how many requirements must be met by injectors used in dual-fuel engines of this type, and the use of both fuels direct injection carried out by one injector would require it to perform tasks that would normally be performed by three, independently operating fuel injectors. In this matter, we are already stopping at the current stage of development of these technologies, because such solutions are currently under research, and even single fuel direct injectors in RCCI engines are revolutionary exceptions for today.

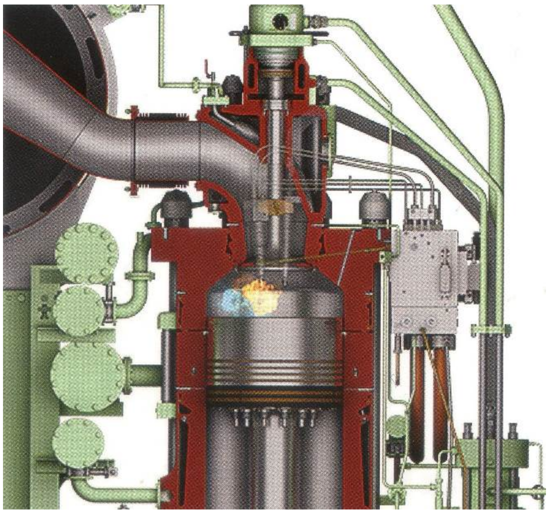


Figure 17 The gas injection or GI-version from MAN B&W for two-stroke crosshead engines in category IV engine.

Source: [3]

Example of such a unique fuel injector is the LNG injector used in MAN B&W for two-stroke crosshead engines in category IV (category of the largest engine size types). Injector applied there is the only existing possibility to inject liquid fuel-gas and diesel fuel into the one combustion chamber in dual-fuel engine. That kind of fuel supply in marine engines are commonly use in two-stroke engines too, but, direct injection of LNG is realized only by MAN B&W for now [3].

In the figure 17 there is the cross-section of that engine with two injectors of different fuels. Two injectors used in other engines practically always include the injection of two fuels in liquid form, if both of these fuels show such a state of aggregation under normal physical conditions, or direct injection of gaseous fuel when such fuel is used as a low reactive fuel. In large scale engines those solutions are becoming common, but in smaller scale, in engines used in cars and trucks the usage of two independent injectors is rare in RCCI engines.

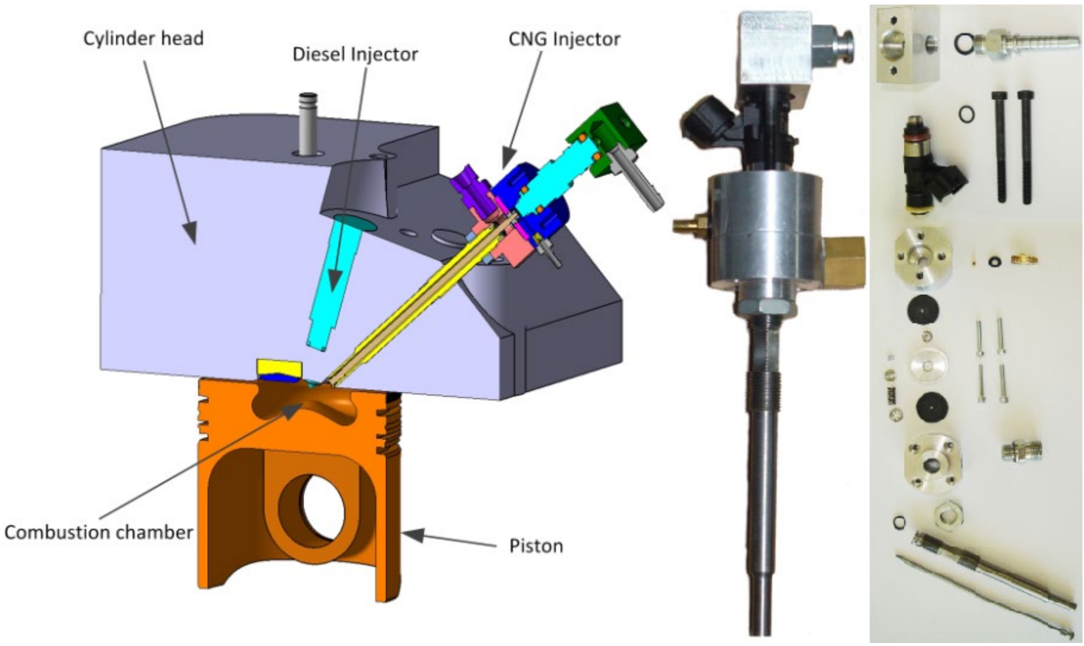


Figure 18 The localisation of the injector in CAD drawing of the cylinder head on the left and a custom gaseous-fuel injector with a parts of it on the right.

Source: [6]

Conception from figure 18 is created at the university research [6]. The dual-fuel engines with direct injection of both fuels for passenger car engines exist only in researcher concept. There is the crafted research injector created for direct injection of gaseous fuel which is shown on the right part of figure 18. Those type of injectors are not commonly used in marine engines. Fuel supply systems where is enough place to install two independent fuel injectors are the most popular in large engines, . Direct injector technology for gaseous fuel is still in developing in every engine size types. In [6] researchers make their own injector for engine research. In the free market it is hard to buy gaseous fuel injector, and basically impossible to buy dual-fuel injector – designed to inject two types of fuels simultaneously. In the figure 18, on the left side of the picture is showed the cross-section of the cylinder head with gaseous fuel injector and connection block, which is used for gaseous fuel supply for the injector. On the right side there is the research injector with parts used for its build. The idea was to create direct injection gaseous fuel injector which can be used in dual-fuel engine, because there are no such products on the market. The problem could be still the shape of injection spray, when in a lot of RCCI engines so simply option of injection quite straight into the combustion chamber is not desirable.

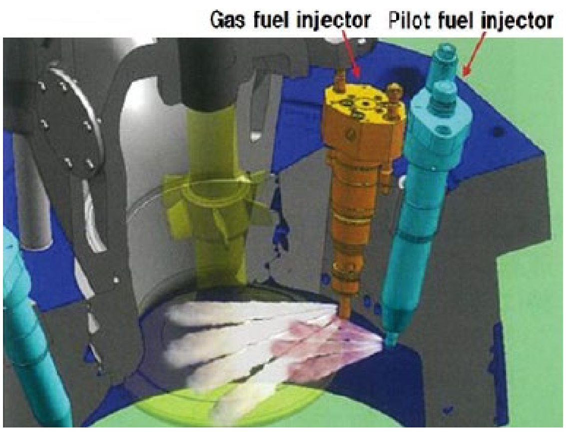


Figure 19 Cylinder cover design for two-stroke dual-fuel engine.

Source: [7]

In the figure 19 the visualisation of two independent injectors shows the possibility of injecting high and low reactivity fuels directly into the combustion chamber at the right angle, enabling coverage of the entire space in the combustion chamber by both fuels used in the dual-fuel engine.

Last undescribed here parameter is the pressure of the injection. This parameter is extremely important for the formation of the air-fuel mixture. For diesel fuel injection that parameter was maximized by introducing the common-rain injection system, where a single fuel line tank supplies diesel fuel under high pressure, ready for injection it to all of the cylinders in the CI engine. The same idea is being used in the direct injection of gaseous fuels.

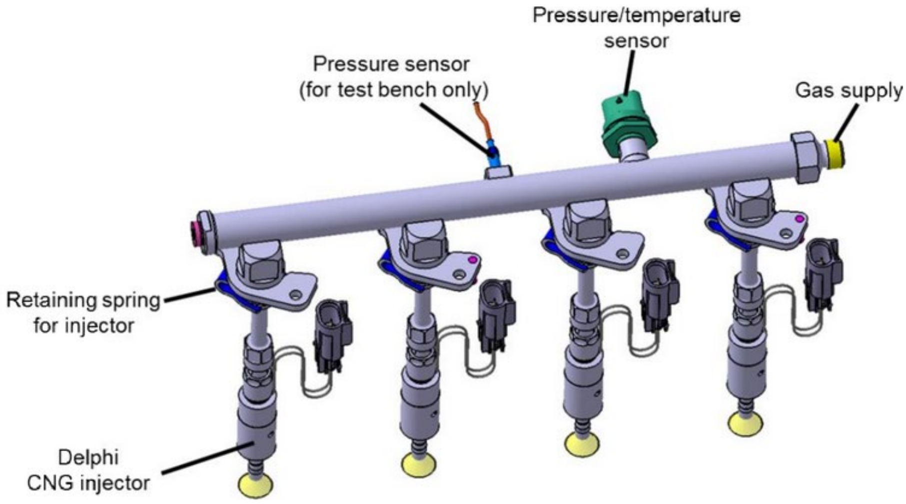


Figure 20 Common rail system for gaseous fuel – CNG – from Delphi company.

Source: [8]

The same type of injection system is available for gaseous fuel – an example can be common rail system for CNG fuel showed in the figure 20. The common rail system for CNG fuel is a promising technology that could help in the future to introduce a dual-fuel direct injection system into common use in the piston engines. It has proven itself well in supplying diesel engines, so probably the future of gas supply to internal combustion engines will also belong to it.

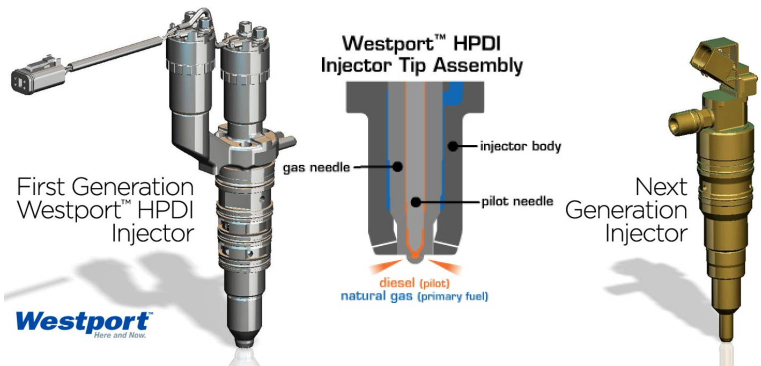


Figure 21 View of two Westport HPDI injectors generations – on the left the older version of injector, and on the right the newest version. In the centre there is a drawing showing a principle of injector operations.

Source: [9], [10]

That possibility to install two injectors for one cylinder in the cylinder head is possible only in larger engines. In small engines to use dual-fuel direct injection fuel supply, often only one fuel injector can be used. In the passenger cars, those type of fuel supply is still not applied yet. In trucks, there is only one manufacturer who supplied dual-fuel engines by one injector. That injector – in two generation options – is showed in the figure 21. HPDI (High Pressure Direct Injection) injector is developing only for few engines dedicated for it [9]. That product is proposed by Westport corporation [11], and described in all relevant publications covering dual-fuel engine solutions for cars and trucks [12]. This is only one factory-made injector available in the global market. Schematic show of direct dual-fuel injection of it, is shown in the middle of the figure 21. Its use offers enormous possibilities in terms of implementing various engine fuelling strategies, but it is only available in a small range of engines from one manufacturer and limited by the and to a limited capacity to a certain extent only available for a specific group of trucks .

3. CONCLUSION

Dual-fuel engines have got diverse types of fuel supply systems. The systems ary for different sizes and uses of engines in which they were applied. Many systems are still under testes and development, especially in smaller engines for passenger cars. Contrary to applications in small engines, dual-fuel supply system are commonly use in marine engines working on ships and in power plant, or manufactories with their own energy generation system based on internal combustion engines.

The very promising technology, which are RCCI engines, requires the use of very sophisticated types of injectors. Injectors of that types are in use only in engines bigger than those used in passenger cars, and access to that solutions is limited.

Supply systems for dual-fuel maritime engines stands at a noticeably higher technical level and allows the use of supply strategies not available for smaller engines. The only upgrade device unavailable in this engine size category is a single multi-fuel injector, although such a product is available for engines used in a certain group of delivery vehicles.

In small size engine categories, the technique of supplying the engine by two independent fuels requires refinement and implementation of technologies already known and working in larger engines. For all engines used in passenger cars in which the dual-fuel technology can be used, intensive development of devices supplying the engine with alternative fuels is required, the use of which allows to reduce CO_2, which emission is strongly limited in passenger cars.

A very important issue is also the development of RCCI engines, which as they develop will constantly require changes and corrections in the method of fuel supply to the engine. The amount of work on the development of fuel delivery systems in RCCI engines will be needed as long as the engines themselves are still in the development stage.

REFERENCES

[1] Masaki Otsu, "Introduction to ME-GI LNG-Fueled 2-Stroke Gas Engine", 2014 environmental seminar documents, Nippon Kaiji Kyokai in Japanese.

[2] Kuiken, K. Gas- and dual-fuel engines for ship propulsion, power plants and cogeneration. Book II: Engine systems and environment, Target Global Energy Training, PJ Onnen, The Netherlands, 2016, 1-544;

[3] Kuiken, K. Gas- and dual-fuel engines for ship propulsion, power plants and cogeneration. Book I: Principies, Target Global Energy Training, PJ Onnen, The Netherlands, 2016, 1-488;

[4] https://dieselnet.com/tech/engine_natural-gas.php#nonpremix

[5] Kuiken K. Gas- and dual-fuel engines for ship propulsion, power plants and cogeneration. Book III: Operation and maintenance, Target Global Energy Training, PJ Onnen, The Netherlands, 2016, 326-327;

[6] Majczak, A.; Barański, G.; Sochaczewski, R.; Siadkowska, K.; CNG injector research for dual fuel engine, Advances in Science and Technology – Reasearch Journal, 2017; 11(1):212–219;

[7] Masaki Otsu, "Introduction to ME-GI LNG-Fueled 2-Stroke Gas Engine", 2014 environmental seminar documents, Nippon Kaiji Kyokai in Japanese.

[8] Husted, H. L.; Guenter K.; Schilling, S.; Weber C. Direct Injection of CNG for Driving Performance with Low CO_2. 23rd Aachen Colloquium Automobile and Engine Technology 2014.
[9] Weichai Westport secures Chinese certification for WP12 natural gas engine powered by HPDI 2.0, Green Car Congress, 2020;
[10] http://www.westport.com;
[11] Rao, A.; Mehra, R.K.; Mehra, R.K.; Duan, H.; Ma, F. Comparative study of the NO x prediction model of HCNG engine, International Journal of Hydrogen Energy 2017, 100084;
[12] Melaika, M.; Herbillon, G.; Dahlander, P. Spark ignition engine performance, standard emissions and particulates using GDI, PFI-CNG and DI-CNG systems, Fuel 2021, 293(7–8);

RESEARCH OF THE MARINE PASSENGER PORT BASED ON A STOCHASTIC MATHEMATICAL MODEL OF THE ARRIVAL OF CRUISE SHIPS

Srećko Krile
University of Dubrovnik
Electrical Engineering and Computing Department
E-mail: srecko.krile@unidu.hr

Nikolai Maiorov
Saint-Petersburg State University of Aerospace Instrumentation
Department of system analysis and logistics
Saint-Petersburg, Russia
E-mail: nmsoft@yandex.ru

UDK 656.021:51
656.615

Summary

Sea passenger port or terminal today is not only a transport infrastructure object, but also acts as a point of development of the region. Having a direct impact the port puts forward new requirements for the improvement of transport infrastructure, makes a significant contribution to the repositioning of the city in the chosen sea region. Today, the development of sea passenger ports and changes in the route cruise and ferry networks are particularly relevant, subject to the restoration of passenger traffic after the gradual removal of restrictions due to Covid-19. This research raises issues of development of sea passenger ports and terminals, changes in route networks of cruise and ferry lines. To solve the problem of strategic planning and change of the port in the sea region, it is necessary to investigate different scenarios. The operation of the passenger seaport directly depends on the flows of cruise and ferry ships entering it, which, is the object of the study. As object of research and modeling, the region of the Baltic Sea and sea passenger port "Passenger Port of Saint Petersburg "Marine Façade" (St. Petersburg) was chosen. As a result of the carried out research the model which is based on the estimation of dynamics of nonstationary traffic intensity with the consequent application of the correlation-regression analysis and the subsequent investigation of characteristics of a random function describing intervals between separate ship calls by means of the method of the greatest likelihood is presented. In practice, the presented new model can be used to justify managerial decisions both on strategic and tactical levels, to assess the effectiveness of investment projects on the development of sea passenger ports and terminals. In addition, the methods described in the article are applicable to the development of new digital transport models of sea passenger ports and terminals.

Keywords: transport processes; mathematical modeling; simulation; ferry network; stochastic model;probabilistic model;non-stationary flow; flow with aftereffect; sea passenger port; cruise ships

1. INTRODUCTION

Today, sea passenger ports and terminals, which are special transport systems, require the development of new models and methods for modernizing infrastructure, assessing the efficiency of port operations, for effective work planning and accurate forecasting of the development of the sea passenger port. It should also be noted that the modernization of port infrastructure and near-terminal urban transport space, the study of interaction models of systems "cruise company - sea passenger port - city" are relevant. These issues are relevant to the ports, which are actively modernizing the infrastructure, introducing new logistics services and, as a consequence, changing both their position in the region and the market, and increasing the attractiveness of the city and the country.

One of the new factors in 2020-2021 that influenced the entire cruise industry is the restrictions caused by Covid-19. This circumstance has formed new requirements, which cause the need to change and restructure internal processes, new requirements for passenger safety in the terminal and, of course, on board the cruise or ferry ship. All these factors influence each other, they are very closely related to each other, which forms a more complex interacting system. The result of this interaction can be reflected in the position and position of the sea passenger port in the area of passenger transportation in the sea region in relation to other ports and changes in the route networks, in relation to this port. Subject to the desire to maximize passenger traffic and increase the intensity of cruise and ferry vessels, port managers need to solve the problems of strategic development, make decisions based on personal experience, which does not always lead to strategically correct development of the port in the region. To make such decisions it is necessary to solve the problem of synthesis of the structure of the sea passenger port [1], complex analysis of passenger transportation technologies, level of development of information technologies, regional and world situation, historical issues of development of each region, assessment of tourist service segment and assessment of changes in the sphere of cruise tourism.

If we consider analytical reports such as "2020 Cruise Industry 101", "MHA 35th Special Magazine" reports [2,3,4], despite the temporary halt in development due to the Covid-19 pandemic, companies forecast a significant increase in market capacity and demand in the cruise and ferry sea passenger transport sector. According to the analytical report presented in [5,6,7,8], the forecast of the number of cruise ships and the capacity of the market will be as follows (fig. 1, 2).

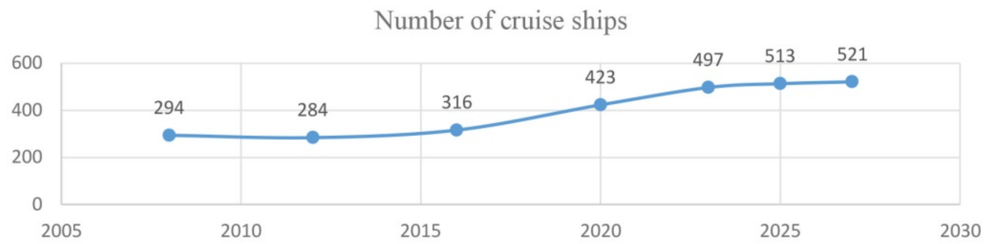


Figure 1 Forecast data on the global number of cruise ships (source: MHA 35th Special Magazine. Cruise industry 2020, Cruise Industry 101)

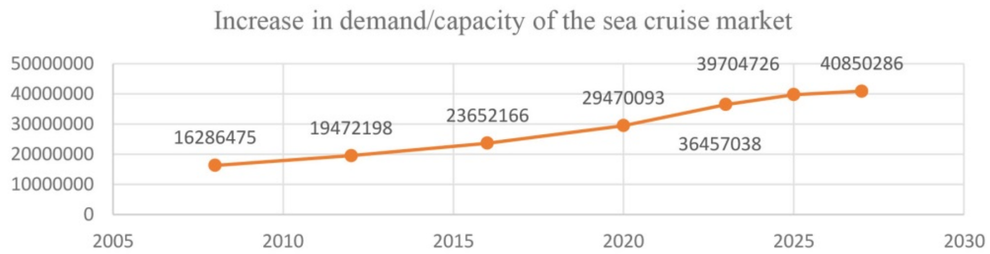


Figure 2 Forecast data on market capacity (source: MHA 35th Special Magazine. Cruise industry 2020, Cruise Industry 101)

While the forecasting cruise ship counts are based on plans to bring new cruise ships into service, the market capacity forecast (Figure 2) likely does not fully reflect the current situation due to Covid-19 restrictions. Increased demand and recovery will be gradual, but passenger handling processes will change due to new requirements for passenger safety. According to the data presented (Fig. 2) we can say that seaports and terminals need to modernize and increase infrastructure if they seek to change their role in the seas and passenger transport market, which is especially relevant in the current situation of industry restart.

The article [9] presents a model for determining the position of a sea passenger port in the sea region, based on the use of "Circos" model. In the presented model, special attention is paid to the analysis of the intensity of calls of cruise and ferry ships to the selected ports and terminals.

The Baltic Sea region was chosen as the object of research. The cruise industry in the Baltic Sea has changed significantly in recent years. Today, the Baltic Sea is the largest market segment in Northern Europe. The Baltic Sea region is extremely diverse in terms of economy, environment and culture, historical sites, but the countries in many cases use common (shared) resources and are interdependent. In this case, passenger and accompanying cargo-passenger maritime transport in the Baltic Sea act as systematic elements.

The main initial parameters for the study of the seaport infrastructure are the incoming flow of cruise and ferry ships, the size of cruise and ferry ships, their passenger capacity, time of their mooring and handling, route ferry networks. During construction of every seaport there are calculated analytical models corresponding to the normative number of berths and intensity of ship calls. As a rule, after certain interval of time it is necessary to change port infrastructure, extend berths for possibility of mooring of larger cruise vessels.

For example, the "Passenger Port of Saint Petersburg "Marine Façade" (city of St. Petersburg) has passed these stages of development [10]. Founded in 2007 to change the position of St. Petersburg in the region, increase passenger traffic and increase the intensity of cruise and ferry ships, the port has undergone more than three global modernizations, the allocation of a separate ferry terminal " Morskoj vokzal" and the expansion of logistics services. For example, in response to the influence of the external environment and competition between ports and terminals, since 2021 the port is expanding its line of services and opens up the possibility to handle cargo flows. The port accepts all kinds of rolling cargoes, optionally - container and refrigerated cargoes. All basic operations have been implemented: cargo loading/unloading, temporary storage and surface handling of consignments. Introduction of a new complex of services became possible thanks to implementation of the project within the framework of the program of cross-border cooperation "Russia - South-East Finland" on reconstruction of a checkpoint in the sea passenger port of St. Petersburg to provide possibility to use the infrastructure of the sea terminal and checkpoint for performance of operations connected with reception of cargo vehicles transported by ferries.

The authors' article [1] presents different models of sea passenger ports development, different stages of route networks development on the basis of detailed analysis of such models as "Anyport", "Workport" model, "three generations" models [11,12,13,14]. On the basis of the analysis of these models the necessity of study of cruise and ferry ships entrance flow intensity and determination of dependence on port infrastructure is determined. In view of attraction of new cruise routes, port managers need accurate understanding of port infrastructure capabilities. This problem should be solved only on the basis of modeling and development of new digital transport models, which will allow to solve the problem of forecasting the development of the seaport, taking into account external environment factors and taking into account possible stochastic processes.

2. RESEARCH OF THE INCOMING FLOW OF CRUISE AND FERRY SHIPS

Cruise and ferry ship flows, transport flows, are a key element of the external environment of the port, the availability of which is a prerequisite for its continuous activity. Therefore, the characteristics of transport flows, in particular their intensity, stability and trends, directly depend on the total workload of the passenger port and, as a consequence, the efficiency and uniformity of the use of all its resources. Study of flows and development of their mathematical models can significantly increase the efficiency of port management and its resources both on strategic and tactical and operational levels. The key role in such research should be played by stochastic models, which allow to take into account the factor of uncertainty and to characterize its influence on the port's activity. Using these models it is possible to increase reliability of port systems operation. In spite of existence of schedule of ship calls, coordination of schedules and plans in advance, when solving the problem of development forecasting, it is necessary to move to modeling of different scenarios. And modeling based on digital transport models.

The flow of traffic has a significant impact on the operation of the port. For example, based on notices from captains of ships about expected time of arrival, the port plans for their maintenance, loading and unloading operations, entering the relevant information into monthly and ten-day schedules, allocates the necessary resources. Port personnel and services strive to streamline ferry vessel handling to ensure the most efficient operation and use of resources. It was noted that the use of traditional management methods does not allow to fully level the impact of the randomness factor of ship calls on its activities. In connection with this fact, the actual task is to develop methods and models for estimation of probabilistic parameters of vessels' flows and connected with them passenger and cargo streams that will allow, subsequently, to lower essentially uncertainty level. First of all it is necessary to estimate available intensity of ship calls of cruise and ferry vessels. In the table 1 the statistics of ship calls “Passenger Port of Saint Petersburg "Marine Façade” on each month in which navigation was carried out in 2015-2019 (according to open schedule data [10]) is brought.

Table 1 Statistics of “Passenger Port of Saint Petersburg "Marine Façade” ship calls from 2015 to 2019 (source: statistics Passenger Port of Saint-Petersburg, Marine Façade [10])

	2015	2016	2017	2018	2019
April	0	0	0	1	1
Май	35	36	42	47	47
June	54	44	57	63	54
July	60	61	68	54	68
August	54	45	56	65	58
September	22	20	21	34	31
October	4	3	5	7	7
November	0	0	0	0	0
December	1	0	0	0	0
Total	230	209	249	270	265

Based on the study of the size of cruise and ferry ships, and loading berths, we determined the graphical dependence of the load of individual berths “Passenger Port of Saint Petersburg "Marine Façade” (Fig. 3) and determined the graphical dependence of the distribution of mooring time liners in the port in 2019 (Fig. 4).

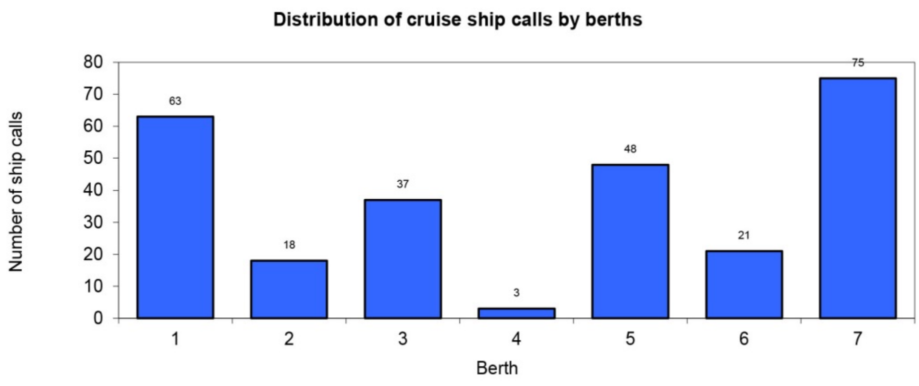


Figure 3 Distribution of cruise and ferry ship calls at “Passenger Port of Saint Petersburg "Marine Façade” berths in 2019 (source: Passenger Port of Saint-Petersburg, Marine Façade [10])

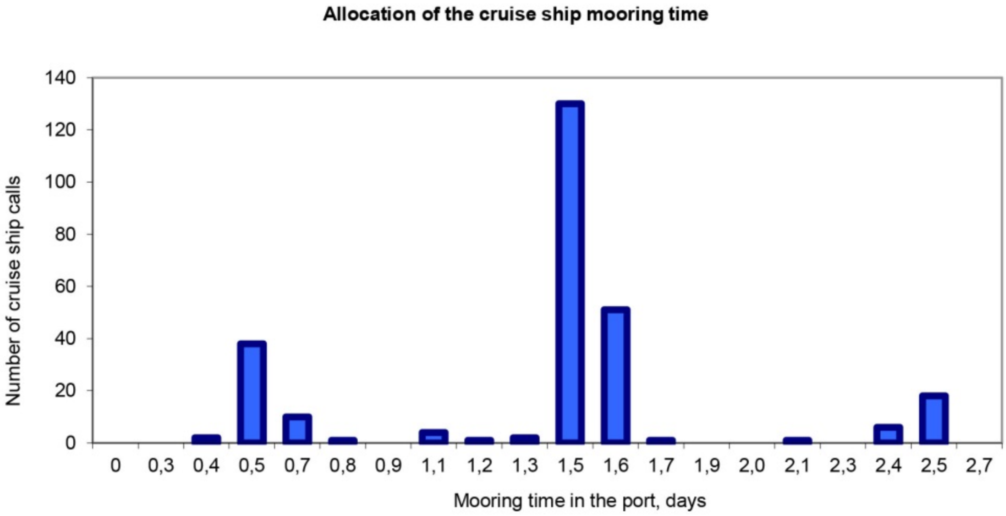


Figure 4 Distribution of liner mooring time in the port in 2019 (source: https://www.portspb.ru/en/Ships_Schedule)

Based on the analysis of cruise ship size and tonnage, it was found that most cruise ships were over 218 meters in length, almost half of which were over 288 meters. As a consequence, there should be an increased load on Berths 1 and 7. Besides, these berths are located closest to the sea, which simplifies maneuvering operations. This is confirmed by the diagram of vessel distribution by berths, shown on fig. 3. In fact, large vessels with berths 1 and 7 busy are docked at berths 3 and 5. This configuration can accommodate the largest number of large liners in the port. Berth number 4 very rarely receives ships, only 3 for all of 2019.

3. A STOCHASTIC MATHEMATICAL MODEL OF THE ARRIVAL OF OF CRUISE SHIPS TO THE SEAPORT

The following steps are necessary to investigate ways to modernize the infrastructure of sea passenger port:

1. a study of the current position of the port in the sea region;
2. identification of competitive strengths and weaknesses of the port;
3. analyzing the existing route network of ferry and cruise lines;

4. formation of new goals of the port development and carrying out multi-criteria modeling. And use of analytical models gives very limited solution (solution applicable for short-term planning)

Modeling of different scenarios is necessary for forecasting the development and justification of infrastructure changes [15,16,17].

The classical model of traffic intensity estimation (applications in the system) is based on the Poisson law of distribution [18,19], hence, the interval between ship calls obeys an exponential distribution with density:

$$f_k(t) = \lambda e^{-\lambda t}, \tag{1}$$

It is known that Poisson flow is stationary, ordinary and has no aftereffects. If cruise ships work on the line, then the time of their call in the port is known with a certain accuracy, which indicates the presence of an aftereffect. Nevertheless, it is not excluded the action of adverse accidental factors, which can lead to delay in the arrival of the ship, as well as the possibility of relatively small deviations from the schedule. In addition, if the port is connected to the sea routes by an approach channel, the movement through which is specially regulated (e.g. caravans), this can also cause aftereffects. It can be taken into account by determining the interval between ship calls according to Erlang's law [17,18] with density:

$$f(t_v) = \frac{\lambda \cdot (\lambda t_v)^{r-1} e^{-\lambda t_v}}{(r-1)!}, \tag{2}$$

where $t_v \geq 0$ — interval between vessel calls for a stream with aftereffects; λ intensity of cruise ship traffic; r — Erlang's order of distribution ($r \in N$, N — set of natural numbers).

The greater the order of the Erlang distribution, the greater the consequence of the flow. When $r = 1$, the distribution is reduced to an exponential distribution.

In fact, the intensity of motion is not constant and can change under the influence of various environmental factors, which can cause aftereffects. When modeling in a digital environment, at the expense of computing power we can consider not only the stationary flow, but also stochastic, taking into account the aftereffects of various external factors. In calculations, it can be taken into account by considering the arrival of ships on the basis of the gamma distribution [18].

$$f(t_v) = \frac{\lambda \cdot (\lambda t_v)^{r-1} e^{-\lambda t_v}}{\Gamma(r)}, \tag{3}$$

where $t_v \geq 0$ — interval between ship calls of cruise ships; λ — input flow intensity; r — distribution order ($r > 0$); $\Gamma(r)$ —gamma-function.

Taking into account the above considered properties of the flow of ships, let us assume that the intervals between their calls are subject to exponential or gamma distribution, but the intensity λ will be assumed to be variable. Then, in order to correctly model the flow of cruise ships it is necessary to perform the following actions:

1) collect statistical data on the vessels' calls to the port for a certain period of time and group them by directions of transportation;
2) divide considered time interval into intervals and for each of them to calculate the intensity of the flow of ships as a ratio of the number of ship calls during the interval to its duration (allows to see a clear and stable dynamics);
3) determine a function that characterizes with sufficient accuracy the dependence of the intensity of the flow of ships on time;
4) to estimate the degree of consequence of random ship calls (parameter r in formulas (2) and (3));
5) test the statistical hypothesis that the empirical data correspond to the selected distributions by using the criterion of agreement;
6) input the obtained data into the simulation model

It is convenient to study intensity function from time by empirical data using correlation and regression analysis. At that, it is possible to use both intensity values on the chosen time intervals, and its values for each pair of "neighboring" ship calls (in this case it is the value inverse of the interval between them).

Having received the intensity function, we can proceed to the analysis of the non-stationary flow of ships. Let's consider the final mathematical model. If the interval obeys gamma-distribution, then its probability density function for unsteady flow is defined according to the expression:

$$f(t_v) = \frac{\lambda(t_0 + t_v) \cdot (\Lambda_{t_0, t_0 + t_v})^{r-1} e^{-\Lambda_{t_0, t_0 + t_v}}}{\Gamma(r)}, \quad (4)$$

The formula for estimating r with known λ can be determined from the following relation, $r = \lambda \bar{t}$, where $\bar{t}$ - sample average (average interval between ship calls of cruise ships).

4. SIMULATION RESULTS OF THE INCOMING FLOW OF CRUISE SHIPS AND EVALUATION OF THE PORT INFRASTRUCTURE FOR MODERNIZATION

The obtained model proved its efficiency with schedules of ship calls of “Passenger Port of Saint Petersburg "Marine Façade”. Based on the initial data of cruise ship call intensities the experiments with intensities of ship arrivals were made in accordance with mathematical distributions. Vessel mooring times are distributed according to the real distribution. The simulation time is 1 year, and the average intensity is taken for ship arrivals in 2019 - 265 ships per year. Comparison of the results of model runs with different types of distributions is presented in Table 4.

Table 4 Comparison of distribution types.

	Distribution		
Number of occupied port berths	Poisson	Normal	Gamma
0	0.36	0.36	0.35
1	0.39	0.37	0.41
2	0.16	0.2	0.16
3	0.06	0.05	0.07
4	0.02	0.02	0.01
5	0	0	0
6	0	0	0
7	0	0	0
Passenger port load factor	0.139	0.142	0.142

The next step was to build a digital model of the sea passenger port in AnyLogic environment and perform a number of optimization experiments to find the best parameters of cruise ship and ferry vessel call intensity. The results of the optimization experiment are shown in Table 5.

Table 5 Results of optimization experiment in AnyLogic software environment

	Distribution		
	Poisson	Normal	Gamma
Maximum intensity of cruise and ferry ships, units	544	530	546
Factor of loading of the sea passenger port	0.303	0.29	0.302

The result of the optimization model is shown in Fig. 5.

Figure 5 The results of cruise ship intensity optimization under gamma distribution

The developed model allows to test any schedule of ship calls and arrival of cruise ships without schedule, according to theoretical distributions. The results of the model are the intensity of ship flow, distribution of vessel mooring time at berths, distribution of vessels by berths, and loading factors of the whole port and individual berths. The data obtained have completeness and allow to investigate any scenario that would require infrastructure modernization. The developed model can also be used to verify the selected vector of development of the sea passenger port.

5. CONCLUSION

To conduct the study, experiments were conducted based on the actual schedule of the "Passenger Port of Saint Petersburg "Marine Façade" for 2015-2019 and separately for 2019. From the graphs of arrivals in the model we can note that the intensity of arrivals according to the schedule was modeled correctly. Also, the diagrams of distribution of ships by berths and mooring times correspond to those obtained in the schedule analysis. In addition, the models calculated the occupancy of a certain number of berths, from 0 to 7 berth, and the loading factor of the entire port and individual berths.

The probabilities of the port states are close to the experimental loadings, but differ in some places. This is due to the fact that the theoretical value does not take into account the night time, when ships are least likely to call the port, and the calculation of loading in the model is discrete and some data may not be taken into account in the software implementation.

The greatest intensity of the flow showed the use of the gamma distribution. As mentioned earlier, this type of distribution takes into account aftereffects in vessel arrivals and describes nonstationary flow more accurately than Poisson distribution. In this connection, the maximum intensity of ship arrivals to the port at its current operating parameters can be considered a gamma-flow with the intensity of 546 ships per year.

The received model has proved its efficiency with schedules of ship calls of port "Passenger Port of Saint Petersburg "Marine Façade" and can be applied to other ports and terminals. Using this model and realization of the digital twin of the sea passenger port opens the possibility to evaluate the modernization of the port infrastructure depending on the position of the port of the region and the influence of the external environment.

REFERENCES

[1] Krile, S., Maiorov, N., Fetisov, V.: Modernization of the Infrastructure of Marine Passenger Port Based on Synthesis of the Structure and Forecasting Development, Sustainability, 2021, 13, 3869, https://doi.org/10.3390/su13073869

[2] *MHA 35th Special Magazine. Cruise industry 2020.* Available at: https://www.cruiseindustrynews.com/pdf/ (accessed 05.06.2021).

[3] Goran Ć., Ivan, P., Dejan, T.: Cruise port passenger flow analysis: A cruise port governance perspective. ,NAŠE MORE, 2020, 67, 181–191. DOI 10.17818/NM/2020/3.1

[4] *Cruise Industry 101.* Available at: https://www.cruiseindustrynews.com/pdf (accessed 15.04.2021).

[5] Stojanović, M., Jugović, T. P., Jugović, A.: Indicators of passenger flows movements on the world and Mediterranean cruise market, Scientifi c Journal of Maritime Research, 2014, Vol. 28, pp. 40-48.

[6] Brida J-G et al. Cruise Passengers in a Homeport: A Market Analysis. Tourism Geographies: An International Journal of Tourism Space, Place and Environment, 2013, Vol 15, pp. 68-87. DOI: 10.1080/14616688.2012.675510.

[7] Esther, V., Jose Ramon, G., Joaquim, M., Javier, R., Jordi, S.: Economic Impact of Cruise Activity: The Port of Barcelona; IREA Working Papers; University of Barcelona, Research Institute of Applied Economics: Barcelona, Spain, 2016.

[8] Petrick, J., Li X. & Park S-Y.: Cruise passengers' decision-making processes, Journal of Travel & Tourism Marketing, 2007, Vol. 23, N. 1, pp. 1-14.

[9] Maiorov, N.N.: Work analysis of maritime passenger terminals for particular region based on circos plot, Naše more (Our Sea), 2019,Vol 66, No 2, pp. 57-61, DOI 10.17818/NM/2019/2.2

[10] *Passenger Port of Saint-Petersburg, Marine Façade.* Available at: https://www.portspb.ru/ (accessed 11.03 2021).

[11] Keng, B.L.: Port Development; UNCTAD: New York, NY, USA, 1985.

[12] Bird, J.: Seaports and Seaport Terminals; Hutchinson University Library: London, UK, 1980.

[13] Port marketing and the Challenge of the Third Generation Port. New York: UNCTAD, 1994, 55 p

[14] Beresford, A. K. C., Gardner B.M., Pettit S.J., Naniopoulos A., Wooldridge C. F.: The UNCTAD and WORKPORT models of port development: evolution or revolution?, Maritime Policy and Management, 2004, Vol. 31., Is. 2., pp. 93–107.

[15] Pallis, A. A., Rodrigue, J. P., Notteboom, T. E. Cruises and Cruise Ports: Structures and Strategies, Research in Transportation Business & Management, 2014, Vol. 13, pp. 1-5. https://doi.org/10.1016/j.rtbm.2014.12.002

[16] Tsamboulas, D., Moraiti, P., Koulopoulou, G.: How to Forecast Cruise Ship Arrivals for a New Port-of-Call Destination, Transportation Research Record: Journal of the Transportation Research Board, 2013, No. 2330, pp. 24-30. https://doi.org/10.3141/2330-04

[17] Yan, S.; Chen, H.C.; Chen, Y.H.; Lou, T.C. Optimal scheduling model for ferry companies under alliances, J. Mar. Sci. Technol, 2007, 15,pp. 53–66.

[18] Ventzel, E.S. , Ovcharov L.A. : Teoriya sluchajnyh processov i ee inzhenernye prilozheniya [Theory of Random Processes and its Engineering Applications]. Moscow: Nauka, 1991. 384 p. (In Russian)

[19] Dragovic, B. , Park N.K., Radmilović Z., Maraš V. :Simulation Modelling of Ship-Berth Link with Priority Service , Maritime Economics &Logistics, 2005, Vol. 7, Is. 4, pp. 316-335, DOI: 10.1057/palgrave.mel.9100141.

SWOT ANALYSIS OF SHIP ENERGY EFFICIENCY MANAGEMENT PLAN (SEEMP)

Ivica Krmek
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: ivica.krmek@unidu.hr

Tonći Biočić
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: tbiocic.tb@gmail.com

Srđan Vujičić
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: srdjan.vujicic@unidu.hr

Nermin Hasanspahić
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: nermin.hasanspahic@unidu.hr

UDK 504.5:621.43.068

Summary

With large amounts of harmful gases being released into the atmosphere from ships, the maritime industry has come under the scrutiny of regulators, who are becoming increasingly concerned about the problem of global carbon emissions. Carbon emissions could be significantly reduced if operational efficiency on ships is improved, so the International Maritime Organization (IMO) has enacted a series of regulations that will increase the energy efficiency of ships themselves and reduce their environmental impact as much as possible. One of the adopted provisions is the International Energy Efficiency Certificate (IEEC). For a new ship to obtain this certificate (contract placed on or after 1 January 2013), it must meet the Energy Efficiency Design Index (EEDI) and must also have a Ship Energy Efficiency Management Plan (SEEMP). Older ships must have a SEEMP, an operational measure to improve the energy efficiency of ships and applies to all ships of 400 GT or more on international voyages. This paper aims to analyze the plan for improving the energy efficiency management of ships. Furthermore, this paper aims to use SWOT analysis to identify the advantages and disadvantages of SEEMP and propose recommendations for improving energy efficiency management system.

Keywords: SEEMP, EEDI, carbon emissions, shipping

1. INTRODUCTION

As the usage of fossil fuels has accelerated global warming, which has caused many problems, such as climate change, and damage to ecosystems worldwide, there has been a need to reduce emissions [1]. Although the maritime industry is the least polluting of all transport industries, reducing emissions from ships can significantly contribute to solving the problem [2]. Therefore, the International Maritime Organization (IMO) acted through MARPOL and other regulatory instruments to improve ships' energy efficiency, reduce greenhouse gas emissions in shipping, and develop technical (EEDI) and operational measures (SEEMP) for that goal [3,4,5]. Marine Environment Committee (MEPC) deals with environmental issues under the remit of the IMO. The Energy Efficiency Design Index (EEDI) is a technical measure developed to regulate and improve the energy efficiency of newbuild ships and promotes the usage of more energy-efficient and less polluting equipment and marine engines [4,5]. "The EEDI is an index that indicates the energy efficiency of a ship in terms of gCO_2 (generated) / tonne.mile (cargo carried); calculated for a specific reference ship operational condition" [6]. The intention is that by imposing restrictions on this index over time, the need will be created to introduce new energy-efficient technologies in the maritime industry, namely on ships. Shipbuilders and other stakeholders can choose any technology that meets the EEDI requirements for a particular type of ship during shipbuilding. Over time, EEDI will reduce, with plans to create more energy-efficient ships. It applies to all ships engaged on international voyages for which a building contract is placed on or after 1 January 2013. There are Required EEDI and Attained EEDI [6]. To calculate Required EEDI, it is necessary first to obtain Reference EEDI.

Reference EEDI is developed using regression analysis on a large number of data from ships (see Resolution MEPC.231(65) and Resolution MEPC.233(65)). Reference EEDI is calculated using formula (1), where coefficients a, b and c are obtained through regression analysis.

$$Reference\ EEDI = a \times b^{-c} \quad (1)$$

Table 1 presents coefficients a, b and c for some ship types.

Table 1 Coefficients used to determine EEDI Reference value

Ship type	a	b	c
Bulk carrier	961.79	DWT of the ship	0.477
Gas carrier	1120.00	DWT of the ship	0.456
Tanker	1218.80	DWT of the ship	0.488
Container ship	174.22	DWT of the ship	0.201
General cargo ship	107.48	DWT of the ship	0.216
Refrigirated cargo carrier	227.01	DWT of the ship	0.244
Combination carrier	1219.00	DWT of the ship	0.488
Ro-Ro cargo ship (vehicle carrier)	$(DWT/GT)^{-0.7}$ x 780.36 where DWT/GT<0.3	DWT of the ship	0.471
	1812.63 where DWT/GT≥0.3		
Ro-Ro cargo ship	1405.15	DWT of the ship	0.498
Ro-Ro passenger ship	752.16	DWT of the ship	0.381
LNG carrier	2253.7	DWT of the ship	0.474
Cruise passenger ship having non-conventional propulsion	170.84	GT of the ship	0.214

Source: [6]

Required EEDI is calculated based on the following formula (2) [6]:

$$Required\ EEDI = \left(1 - \frac{x}{100}\right) \times (Reference\ EEDI) \quad (2)$$

X is the EEDI reduction factor as agreed and recorded in Regulation 21, and Required EEDI is the limit of the ship's EEDI as per regulations that the actual EEDI must not exceed. As per Regulation 22, the Attained EEDI, which is the actual one, calculated by the shipyard and verified by the Recognized Organization (RO), must always be equal or less than the Required EEDI (formula 3) [6].

$$Attained\ EEDI \leq Required\ EEDI \quad 3)$$

Attained EEDI is the actual EEDI of a particular ship as calculated by the EEDI formula. According to Regulation 20 of MARPOL Annex VI Chapter 4 [6]:

- "The Attained EEDI must be calculated for each new ship, each new ship when undergoes a major conversion or existing ships that undergo so many changes as according to judgment by Administration can be considered as a new ship".
- "The Attained EEDI is only applicable to a large number of ship types but not all ships. For example, fishing vessels are not required to have an Attained EEDI".
- "The Attained EEDI must be calculated considering relevant IMO guidelines" as set in IMO Resolution MEPC.203(62) Chapter 4, Regulation 20.
- "The Attained EEDI must be accompanied by an EEDI Technical File that contains the information necessary for the calculation of the attained EEDI, and that shows the process of calculation".
- "The Attained EEDI must be verified, based on the EEDI Technical File, either by the Administration or by any organization duly authorized by it".

Besides EEDI, IMO has realized that there is a need to introduce a similar index for older ships. During MEPC 76th session (10-17 June 2021), it was agreed that Energy Efficiency Existing Ship Index (EEXI) would be applicable from the first annual, intermediate or renewal International Air Pollution Prevention (IAPP) survey after 1 January 2023. During the session, MEPC adopted guidelines on the methodology of the EEXI calculation, guidelines on EEXI survey and certification, guidelines on the shaft/engine power limitation system to comply with the EEXI requirements [7].

Because EEDI is required only for new ships and EEXI will be mandatory after January 2023, as already stated, there was a need to improve the energy efficiency of older ships as well. The Ship Energy Efficiency Management Plan (SEEMP) is the operational measure aiming to regulate and promote the energy efficiency of all ships, especially existing ones [4]. The SEEMP enables shipping companies to manage the specific ship and whole fleet efficiency performance over time using the Energy Efficiency Operational Indicator (EEOI) as a monitoring tool, which is not mandatory. The guidance on developing the "SEEMP for new and existing ships incorporates best practices for fuel-efficient ship operation and guidelines for voluntary use of the EEOI for new and existing ships "[8]. The EEOI facilitates operators to measure a ship's fuel efficiency in operation and determine the effect of any changes in operation. The Ship Energy Efficiency Management Plan has been developed through detailed discussions between the Member States and with the advice and assistance of the international maritime industry through a specialized working group on greenhouse gas emissions convened by the MEPC [6]. According to Regulation 22 of MARPOL's Annex VI, all ships involved in international voyages larger than 400 GT, from 1 January 2013 must have a SEEMP, which should be developed following the guidelines prescribed by the IMO [5]. "The vote resulted in the adoption of mandatory measures to reduce greenhouse gas (GHG) emissions from international shipping by Parties to MARPOL Annex VI representing the first-ever mandatory global GHG reduction regime for an international industry sector" [9]. It should indicate some options that should be considered if the efficiency of the ship itself is to be increased. As the amendments to MARPOL Annex VI require straightforward implementation of the rules, Resolution MEPC.213(63) (adopted 2 March 2012) takes the following steps to ensure sufficient time for implementation [10]:

- Adopts guidelines for the development of an energy efficiency management plan (SEEMP)
- Invites relevant administrative bodies to take into account guidelines when developing and prescribing national legislature
- Requests the signatories to Annex VI of MARPOL and other administrative authorities to inform masters, seafarers, shipowners, and those concerned with this guidance.
- Agrees to revise guidelines based on experience gained.
- Revokes previously distributed guidelines MEPC.1/Circ.683.

The guidelines adopted by this resolution serve primarily to assist in the preparation of the SEEMP. The guidelines also contain measures that have proven effective in practice to improve ship efficiency. It should be emphasized that the guidelines should be adapted to the characteristics and needs of individual companies and ships, as the same measures may not be appropriate for different companies and different ships of the same company. The final adopted resolution on guidelines for developing a ship's energy efficiency management plan was adopted on 28 October 2016 under MEPC.282(70), replacing the previous MEPC.213(63) [11]. During MEPC 76th session, it was adopted that the SEEMP will have to be enhanced (EEXI), whereby an approved SEEMP needs to be kept onboard from 1 January 2023 [7].

Compliance with the new regulations on air emissions will be one of the biggest challenges for the shipping industry in the future. Shipping companies are already under pressure to reduce energy consumption to meet SEEMP, EEOI and EEDI regulations. Voluntary standards such as ISO 50001, *Energy management systems – Requirements with guidance for use* and associated standards among others ISO 50002, *Energy audits – Requirements with guidance for use* ISO 50003, *Energy management systems – Requirements for bodies providing audit and certification of energy management systems* ISO 50004, *Energy management systems – Guidance for implementation, maintenance and improvement of an energy management systems* are increasingly being used to demonstrate achievements in reducing consumption to third parties.

In this paper Ship Energy Efficiency Measures are presented and elaborated. The novelty of this paper is the presentation of strengths and weaknesses of SEEMP implementation through SWOT analysis. Another valuable contribution of this paper is shortly elaborating on EEXI, which is the latest IMO measure towards more energy-efficient and environmentally friendly ships.

2. GOALS OF SEEMP

Guidelines adopted for developing a ship's energy efficiency management plan should help steer ships towards reducing global carbon emissions. It is predicted that implementing the measures could significantly reduce fuel consumption and thus CO_2 emissions by 45-50 million tons per year.

The purpose of the SEEMP is to establish a working system for the company and/or ship to improve the energy efficiency of the ship's operation. Therefore, the SEEMP should be ship-specific linked to a broader corporate energy management policy for the ship management company, recognizing that no two shipping companies are the same and that ships operate in a wide range of different conditions.

Many companies already have an Environmental Management System (EMS) in place under ISO 14001 that contains procedures for selecting the best measures for specific ships and then set targets for measuring relevant parameters, along with relevant management features and feedback. Therefore, monitoring the operational environment efficiency should be treated as an integral element of a company's management system.

In addition, companies already developed, implemented, and maintained a ship safety management system (SMS), and the SEEMP may be part of the ship's SMS.

SEEMP seeks to improve the ship's energy efficiency through four steps (Figure 1) [12]:

- Planning,
- Implementation,
- Monitoring
- Self-Evaluation and Improvement

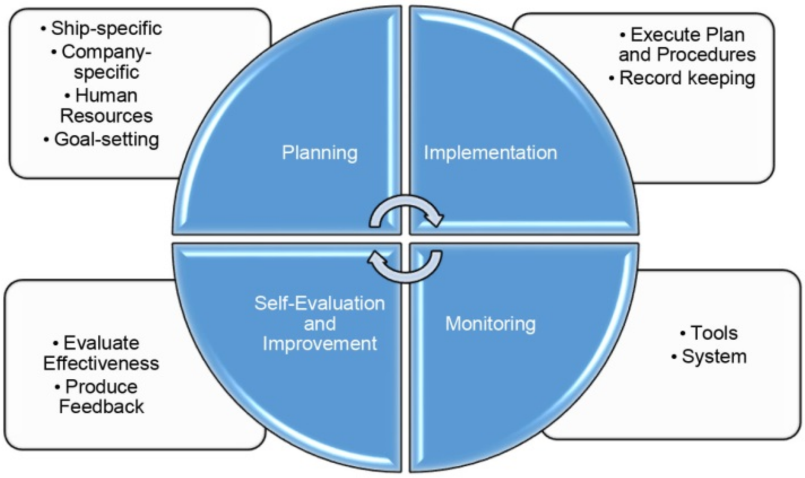


Figure 1 SEEMP phases

Source: Authors as per [13]

SEEMP, therefore, represents a continuous cycle of improving ship energy management. With each iteration of the cycle, some elements of the SEEMP will necessarily change, while some may remain the same. Therefore, it is important to emphasize that safety considerations should always be paramount and always have priority [13].

2.1. Planning

Planning is the most critical phase of the SEEMP, as it primarily determines both the current status of the ship's energy use and the expected improvement in the ship's energy efficiency. Therefore, it is recommended that sufficient time be devoted to planning to develop an appropriate, practical and feasible plan. It is essential to determine and understand the ship's current state of energy consumption during this process. Then SEEMP is used to identify the energy-saving measures taken and determine how effective these measures improve energy efficiency. The SEEMP also determines what measures can be adopted to improve the energy efficiency of a ship further. However, it should be noted that a ship should be viewed as a separate and specific unit when applying specific measures and that measures generally do not have to be the same for every ship.

Improving the energy efficiency of a ship does not necessarily depend only on the shipboard management of a ship itself. It can depend on many factors, including shipyards, ports, shipowners, operators, charterers, cargo owners, and other stakeholders. Increasing coordination among these factors can also contribute to improving the efficiency of the ship itself. Therefore, it is recommended that shipping companies, besides having a ship plan relating to a particular ship, also have a fleet management plan to increase the efficiency of the company's entire fleet.

Human resource development is also an essential element for the effective and stable implementation of the measures adopted, raising awareness and providing the necessary training for staff onshore and onboard ships. Therefore, such human resource development is encouraged and should be an important component of planning.

The last part of planning is setting a goal. It is important to emphasize that the achievement of the goal is not subject to external review, but its purpose should be a signal of whether a particular plan is adequately implemented and whether it brings the expected results in terms of expected energy efficiency.

The target can take any form, such as annual fuel consumption or any other specific target of an operational energy efficiency indicator (EEOI). Whatever the goal is, it should be measurable and easy to understand [13].

2.2. Implementation

Once the ship and the company have determined the measures to be implemented, it is necessary to establish a system for implementing the identified and selected measures by developing energy management procedures. That is achieved by defining specific tasks and appointing qualified staff to carry them out. Therefore, the SEEMP should describe what the measure should be and who is responsible for its implementation.

Also, the period envisaged for implementation must be indicated. The planned measures should be implemented following a predetermined implementation system. Keeping records of the implementation of each measure is helpful for self-evaluation at a later stage and should be encouraged. If a measure cannot be implemented, it is necessary to have written records for internal use [13].

2.3. Monitoring

The energy efficiency of a ship should be monitored quantitatively. Preferably, it should be done by an established method, preferably according to international standards. The EEOI developed by the IMO is one of the internationally established tools for obtaining quantitative indicators of the energy efficiency of a ship and/or fleet and can be used for this purpose. If used, it is recommended that the EEOI should be calculated following MEPC.1/Circ.684 guidelines adapted as necessary for a particular ship or specific ship trading areas. If another tool is used, the concept of the tool and the monitoring methods should be determined in the planning phase. It should be borne in mind that, regardless of which measurement tools are used, continuous and consistent data collection is the basis of monitoring. To enable meaningful and consistent monitoring, a monitoring system, including data collection procedures and the scheduling of responsible staff, needs to be developed. Such a system can be considered part of the planning and should therefore be completed at the planning stage. It should be noted that, in order to avoid unnecessary administrative burdens for shipboard personnel, monitoring should be carried out by as many as possible shore-based personnel, using data obtained from the ship. When a ship deviates from its intended route to engage in search and rescue, it is recommended that data obtained during such operations not be used to monitor energy efficiency and that such data be recorded separately [13].

2.4. Self-Evaluation and Improvement

The final phase of the SEEMP cycle is Self-Evaluation and Improvement. It should produce profound feedback for the upcoming first phase, i.e. planning the phases of the next improvement cycle. The purpose of the self-evaluation is to assess the effectiveness of the planned measures and their implementation to deepen the understanding of the overall energy-efficient operation of the ship. It includes types of measures, their reasons for effective (or ineffective) functioning, understanding the efficiency improvement trend for a specific ship, and developing the improved SEEMP for the next cycle.

For this process, shipboard energy management self-evaluation procedures should be developed. Furthermore, self-evaluation should be conducted periodically using data collected through monitoring. In addition, it is recommended that some effort be made to identify the causes and consequences of the impact during the estimated period to improve the next phase of the management plan [13].

The SEEMP is subject to verification and company audits, and its review must be done by 1 January 2026, during which evaluation of the following will occur:

- Strengthened corrective actions,
- Need for enhancement of the enforcement mechanism.

As the EEXI is being introduced, SEEMP will need to be enhanced and approved [6].

3. ENERGY EFFICIENCY MEASURES ONBOARD SHIPS

The measures adopted and implemented onboard ships in order to increase energy efficiency may relate to the following:

- Optimization of the navigation,
- System optimization in the engine room.

When optimizing for the voyage, the first essential element is the speed of the ship. Upon the ship's departure from the port, the speed is gradually increased to the agreed one (charter party speed). The weather conditions and loads and the manufacturer's recommendations must be taken into account. During the trip, the speed will not fall below the agreed unless weather conditions exceed the agreed descriptions. Then the speed will adjust to the best compromise between energy-saving and safety. These conditions must also be reported to the responsible persons ashore. If the ship was chartered, any change in speed from the contracted one should be confirmed by the charterer and approved by the shipowner.

Another vital element for voyage optimization is passage planning, which may include a weather tracking service. The voyage is planned to take into account all weather conditions, current and available information on the tides in the areas through which the ship will sail, and crewmembers' personal experiences. Selected routes are the shortest routes unless otherwise recommended by publications, a weather service, or for passing through areas prone to piracy. It should be noted that the shortest routes across the ocean may not be the safest at times. Regardless of the routes recommended by the various weather services, the final decision on the voyage route is up to the master. In case of conflict of the chosen route with the route recommended by the weather service, the master is obliged to inform the company to explain his decision.

Furthermore, it is very important to optimize the control of the ship's course and the automatic control function. The steering response is adjusted so that turning movements are limited to a minimum not to increase sailing distance. However, the autopilot settings should not be too stiff; otherwise, frequent rudder movements will increase the load on the main engine and result in an overall lower speed. Depending on the sailing regime (whether the ship is in ballast or loaded condition), the settings of the automatic rudder will need to be adjusted to the conditions. Basically, the setting for economic mode should not change.

An essential element that affects the ship's energy efficiency is the condition and maintenance of the ship's hull. The hull of the ship must be as clean as the ship's propeller. If the ship's speed drops, the ship's hull and propeller cleaning must be considered immediately. Also, if he notices any reduction in speed for which there is no logical explanation, the master must inform those responsible in the company. The last element that significantly affects the ship's efficiency concerning the navigation venture is the amount of ballast on board. This primarily depends on the nature of the trip. However, whenever possible, it should be ensured that the ship's propeller is wholly immersed and that the ship's bow is sufficiently immersed, especially during storms. An additional thing that can be done onboard during the voyage is to pay attention to the energy savings that will significantly save marine fuel for a more extended period.

The first element to be monitored in the engine room is the operation of the main engine. The main engine is maintained according to the manufacturer's recommendations as shown in the ship's Planned Maintenance System (PMS) so that its consumption is as close as possible to the nominal figures measured during experiments in workshops and sea trial, taking into account differences between conditions in which the engine actually operates. It should be borne in mind that the environment of the engine room alone can be up to 50% worse than in the workshop, especially in terms of fuel quality.

The next step is to monitor the operation of all auxiliary engines in the engine room. Auxiliary engines are maintained according to the manufacturer's recommendations to keep their consumption as close as possible to the nominal figures measured during the workshop test and consider the conditions of the actual operating environment of the engine (operating condition and fuel quality). If no more than one generator is required for electricity consumption, then the number necessary for regular operation and life on board shall be kept in operation, and auxiliary engines which are not necessary shall be switched off or put into a standby mode (following manufacturer's procedures for stopping auxiliary engines).

The consumption of cylinder oil and oil required for the operation of the main engine is under constant monitoring to detect any more significant loss than expected at the earliest stage.

One of the more critical factors affecting the energy efficiency system in the engine room is the fuel used by the ship. Reputable suppliers should be used for fuel supply to prevent any fuel quality problems that may adversely affect the performance of the main engine. New fuel received on board is sent for analysis, and only after receiving the results and confirmation that the fuel is of good quality can it be used. Therefore, it is imperative to continuously monitor all major systems in the engine room to act on some negative indicators promptly. Also, the ship's air conditioning system must be regularly maintained to achieve the best ambient air cooling in the range of 22-25 °C. The doors of rooms that are cooled or heated should be kept closed to minimize energy waste.

Training and familiarisation of crewmembers should include instructions on the application of best energy-saving practices. Adequate training is primarily provided as part of the shipboard familiarisation and the duties that each crew member should receive when boarding the ship according to the available schedule in the appropriate manual for the company's safety management system.

The officer responsible for managing the energy efficiency onboard is usually the chief engineer. In addition, he is responsible for the implementation of SEEMP measures. His duties include the following [2]:

- Ensuring the safety of the ship and crew in terms of energy efficiency;
- Ensuring that performance measures are complied with and keeping records of their implementation;
- Ensuring that the ship's crew is educated and aware of the ship's energy efficiency;
- Ensuring that adequate SEEMP records are kept and updated, including energy conservation records;
- Ensuring the availability of the SEEMP and relevant records to the competent authorities;
- Ensuring that the ship's equipment is correct, including the availability of automatic operation mode of all systems having this mode.

He must also inform the master on the following:

- Progress of energy efficiency management operations, and
- Any anticipated deviations from the agreed plan.

The training of crewmembers onboard a ship is made following the company's safety management system through:

- Periodic safety meetings
- Familiarisation of new crewmembers.

Also, the relevant literature (equipment manuals, various publications and legislative) found on ships can be used as a supplement to education related to this issue. Each crewmember must be aware of the importance of applying energy efficiency measures onboard ship because only in a way that everyone onboard acts in accordance with them can result in the satisfactory achievement of planned goals.

Energy-saving record logs are kept on each ship. They include the details of all energy-saving related actions taken onboard to reduce energy wastage and improve the ship's energy efficiency. In the first place, this is necessary to facilitate the analysis of the shipboard energy-saving through specific inspections. During such shipboard inspections, the person authorized by the company will assess the effectiveness of these measures by analyzing record logs and inspecting SEEMP.

The data recorded in the energy-saving logs include the following:

- Replacement of insulation and clamping materials (various seals);
- Installation of equipment with less environmental impact (for example, air compressors with better performance);
- Effective application of new energy-saving practices onboard a ship (lights switched off in uninhabited cabins, radars off when their work is unnecessary, etc.);
- Reporting any problems related to energy efficiency to the company;
- Hand over notes of officers in charge of the shipboard energy efficiency;
- Records of inspections performed by authorized persons of the company;
- Records of SEEMP reviews by the competent organizations;
- Training and education of the ship's crew in order to improve their energy-efficiency awareness;
- Important communication related to this issue.

Each ship needs to have specific measures developed within SEEMP, but it depends on shipboard leadership and crewmembers to implement them and effectively

4. SWOT ANALYSIS OF SEEMP

Although SEEMP was designed to improve ships' energy efficiency and facilitate the shipping industry's transition to a more environmentally friendly one, it has several shortcomings that need to be pointed out. Therefore, the authors compiled its strong and weak points and summarised them in Table 2.

Table 2 SWOT analysis of SEEMP

Strength	*Reduction of CO_2 emissions from shipping*	Weakness	*Significant investments in more sophisticated technologies and more efficient ships*
	Savings in fuel consumption		*Additional paperwork acts as a burden*
	Encouraging the development of new technologies to reduce CO_2 emissions from shipping		*EEOI is not mandatory*
	Improvement of sustainability in shipping		*Additional energy efficiency training for all crewmembers*
	Subject to verification and company audits		*No approval from RO or Flag Administration needed (until the first annual, intermediate or renewal IAPP survey after 1 January 2023)*
Opportunity	*Development of tailored company-specific training ashore*	Threat	*Inadequate energy efficiency familiarisation onboard a ship*
	Introduction of new technologies (blockchain) for shipboard data reports essential for energy efficiency		*Inaccurate and falsified shipboard data reports used to set SEEMP ship specific goals and for implementation control*
	Shipboard leadership sets an example in energy conservation and acts as a role model for crewmembers		*Crewmembers might be unwilling to put extra effort during daily jobs for energy conservation*
	Commitment to implementation and following of SEEMP measures as a tool for marketing strategy (customers might recognize pro-ecological commitment from the company)		*Shipowners' investment in energy-saving devices depends on Return of Investment (ROI) and is highly subject to fuel prices and demand for specific devices and equipment on the market (higher demand - higher price)*

As can be seen from Table 2, SEEMP is a tool enabling and facilitating savings in fuel consumption, which has a double effect: it helps to preserve the marine environment and at the same time saves shipowners or charterers money. Also, new technologies are developed to be able to meet emission regulations and improving energy efficiency. However, significant sums of money need to be invested in new technologies and fuels initially, which might present difficulties for some shipowners. Also, there is a need for crewmembers training to enable adequate implementation of SEEMP measures. Another barrier that might be presented as unfavourable is additional paperwork, which is seen as additional work and presents a headache for some seafarers. The next downside of SEEMP is that it does not need to be approved by Flag Administration or Recognized Organization; it needs to be prepared following IMO recommendations and placed onboard a ship. However, it has to be verified during internal audits, which can be considered as an improvement. Finally, a significant problem might be introducing non-mandatory EEOI, a tool for monitoring energy efficiency over time. It might be argued that without mandatory monitoring tool, there will be ships which will not improve their performance and continue to impact on environment negatively.

5. DISCUSSION AND CONCLUSION

To effectively implement SEEMP into shipping practices, seafarers have to be adequately trained and, if possible, involved in ship-specific SEEMP development. However, one of the weaknesses recognized in our study was additional SEEMP training for all crew members, as Hansen et al. [14] found. In addition, they found that many seafarers were not involved in SEEMP development nor received adequate SEEMP training. Lack of training might result in wrong decisions and thus prevent effective energy efficiency measures.

Another issue that might diminish the complete success of the SEEMP's target could be additional paperwork that acts as a burden on seafarers, who must spend time filling various forms needed to track energy consumption. Ballou, in his paper, proposed a *Total Solution* Approach to the evaluation of the operating efficiency of the ship [15]. SEEMP should be comprehensive and help operators to achieve better performance and facilitate operation. According to him, SEEMP might become just another piece of paper that meets MARPOL Annex VI requirements, or it might generate significant cost savings, on the other hand, constituting profitable ROI. For the best results of SEEMP, the *Total Solution* Approach, amongst others, includes shipboard data acquisition (automated and manual), a method for transmitting the data to shore promptly and continuous "user training and awareness-raising programs" [15]. As recognized in our study, manual data acquisition might constitute an additional paperwork burden for seafarers, and ways to facilitate it must be found and implemented. In this study, the authors proposed introducing new technologies like blockchain, which might be helpful since they could facilitate data collection and enable more accurate and real-time data that could improve ship-specific energy-saving procedures.

Furthermore, additional shore-based and shipboard training and familiarisation are needed to introduce seafarers to possibilities and ways of energy savings onboard ships. Besides training and familiarisation, shipboard leadership should drive necessary changes in crewmembers behaviour to achieve the target set by the SEEMP. According to [16] Master of a ship is responsible for SEEMP training onboard a ship. The Chief Engineer is responsible for monitoring and documenting ship energy efficiency [16]. However, it must be noted that without clear guidance from the company side and development of step-by-step training methodology, inadequate or uncompleted training might be detrimental. In this study, leadership actions might represent opportunities to develop improved energy efficiency actions onboard ships. Therefore, besides training, guidance on documentation needed from Chief Engineer should be clearly stated from the company.

One of the threats recognized in this paper is inaccurate and falsified shipboard reports (noon report, for example). Vorkapić et al., in their paper [17], proposed a machine learning model aiming to predict the energy efficiency of ships. The machine learning model was "learned from shipboard automation system measurement data, noon logbook reports, and related meteorological and oceanographic data" [17]. One of the threats to obtaining accurate and relevant data in the model is shipboard noon reports. One of the developed model's weaknesses was that "part of the data retrieved from the ship's noon reports is based on subjective perception", as the authors recognized in [18]. Human factors and the possibility of changing data should be minimized, and one of the possible solutions is the introduction of sensors and new technologies for obtaining all necessary data for measuring the energy efficiency of a ship.

There are numerous benefits of SEEMP, but the most important one is the significant savings in fuel and thus a significant reduction in harmful gas emissions into the atmosphere. Proper use and monitoring of all marine systems using higher quality fuels and lubricants prolongs the service life of the systems and increases their efficiency. As it can be seen, SEEMP was introduced as an operational measure where the ship's operator was developing a ship-specific energy efficiency plan, following IMO guidelines, but there was no need for a plan to be approved by the Flag state nor the RO. Its presence onboard was only verified during inspections, not its contents, which might present a significant failure. If already implemented by the IMO, SEEMP should be adequately prepared (ship-specific) and include all measures (procedures and systems) needed to improve shipboard energy savings efficiently. Without approval from RO, the SEEMP target itself might be unachievable due to inadequately prepared measures within. The latest MEPC session (76th) realized potential shortcomings and adopted enhancing and approval of SEEMP during the first annual, intermediate or renewal IAPP survey after 1 January 2023. That might positively affect energy savings on existing ships and significantly reduce emissions of harmful gases from ships.

The introduction of EEXI might significantly improve energy savings and environmental protection since it will be a mandatory technical measure included in SEEMP. As EEOI is not mandatory, EEXI will enable the implementation of ship-specific measures and track their effectiveness.

The company's commitment to the SEEMP implementation, continuous monitoring and improvement will undoubtedly result in achieving the set goals. By applying the prescribed measures, ship systems become more efficient, and thus costs are reduced, which are reflected in the company's overall business results. Furthermore, it should be made clear that measures should never be implemented if there is any suspicion that this would jeopardize the ship's safety, as safety nevertheless remains a major and priority factor in the maritime business. The success of SEEMP largely depends on the commitment and effort of the company itself that adopted the SEEMP measures. Thus, the expected success of energy efficiency measures requires the commitment and participation of all stakeholders.

REFERENCES

[1] Nam-Kyun IM; Bora Choe; Chung-Hwan Park. 2019. Developing and Applying a Ship Operation Energy Efficiency Evaluation Index using SEEMP: a Case Study of South Korea. Journal of Marine Science and Application 18, 185-194.

[2] Hüffmeier, J.; Johanson, M. 2021. State-of-the-Art Methods to Improve Energy Efficiency of Ships. Journal of Marine Science and Engineering. 2021; 9(4):447. https://doi.org/10.3390/jmse9040447

[3] Mensah, E. N. O. 2017. Optimizing energy efficiency: split incentives in the context of the implementation of SEEMP. World Maritime University Dissertations. 577. Available online: https://commons.wmu.se/all_dissertations/577 (Accessed 25 April 2021).

[4] Hasanspahić, N.; Vujičić, S.; Čampara, L.; Piekarska, K. Sustainability and Environmental Challenges of Modern Shipping Industry. Journal of Applied Engineering Science 19(2021)2, 802, 369-374.

[5] Čampara, L.; Hasanspahić, N.; Vujičić, S. Overview of MARPOL ANNEX VI regulations for prevention of air pollution from marine diesel engines. SHS Web of Conferences 58, 01004 (2018). GLOBMAR 2018. https://doi.org/10.1051/shsconf/20185801004

[6] International Maritime Organization. IMO Train the Trainer (TTT) Course on Energy Efficient Ship Operation. Module 2 – Ship Energy Efficiency Regulations and Related Guidelines. IMO, London, 2016. Available online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/M2%20EE%20regulations%20and%20guidelines%20final.pdf (Accessed 15 May 2021).

[7] DNV. IMO update: Marine Environment Protection Committee – MEPC 76. Available online: https://www.dnv.com/news/imo-update-marine-environment-protection-committee-mepc-76-203128 (Accessed 18 June 2021).

[8] International Maritime Organization. MEPC.1/Circ.684. Guidelines for voluntary use of the ship energy efficiency operational indicator (EEOI). IMO, 17 August 2009.

[1] International Maritime Organization. Energy Efficiency Measures. Available online: https://www.imo.org/en/OurWork/Environment/Pages/Technical-and-Operational-Measures.aspx (Accessed 30 April 2021).

[9] International Maritime Organization. Resolution MEPC.213(63). 2012 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP).

[10] International Maritime Organization. Resolution MEPC.282(70). 2016 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP).

[11] Bazari, Z. MARPOL Annex VI Chapter 4 – Energy Efficiency Regulations. National Workshop (virtual) on Ratification and Effective Implementation of MARPOL Annex VI for Egypt 25 November 2020. Available online: https://www.rempec.org/en/knowledge-centre/online-catalogue/5-zb-l03-marpol-annex-vi-chapter-4-final.pdf (Accessed 15 May 2021).

[12] American Bureau of Shipping (ABS). Ship Energy Efficiency Measures. Status and Guidance. Available online: https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/ABS_Energy_Efficiency_Advisory.pdf (Accessed 10 May 2021).

[13] Hansen, E.K.; Rasmussen, H.B.; Lützen, M. 2020. Making shipping more carbon-friendly? Exploring ship energy efficiency management plans in legislation and practice. Energy Research & Social Science, 65, 101459.

[14] Ballou, P.J. 2013. Ship Energy Efficiency Management Requires a Total Solution Approach. Marine Technology Society Journal,47(1), 83-95.

[15] Herdzik, J. 2014. Remarks on Implementation of Ship Enargy Efficiency Management Plan. Zeszyty Naukowe Akademii Morskiej w Gdyni, 83, 81-88.

[16] Vorkapić, A.; Radonja, R.; Martinčić-Ipšić, S. 2021. Predicting Seagoing Ship Energy Efficiency from the Operational Data. Sensors, 21(8), 2832. https://doi.org/10.3390/s21082832.

[17] Vorkapić, A.; Radonja, R.; Martinčić-Ipšić, S. 2021. A framework for the application of shipboard energy efficiency monitoring, operational data prediction and reporting. Scientific Journal of Maritime Research, 35, 3-15. https://doi.org/10.31217/p.35.1.1.

THE ROLE OF MULTIMODAL TRANSPORTATION IN ARCTIC SUSTAINABLE DEVELOPMENT: PROSPECTS AND RISKS

Irina Makarova
Kazan Federal University, Russian Federation
E-mail: kamIVM@mail.ru

Ksenia Shubenkova
Kazan Federal University, Russian Federation
E-mail: ksenia.shubenkova@gmail.com

Polina Buyvol
Kazan Federal University, Russian Federation
E-mail: skyeyes@mail.ru

Anton Pashkevich
Politechnika Krakowska, Krakow, Poland
E-mail: apashkevich@pk.edu.pl

UDK 656.022.8 (985)

Summary

Climate change opens up great opportunities for the development of the Russian Arctic. This investment area is a priority for Russia and may have a positive effect. The Arctic development is planned through a system of so-called "support zones", which differ in the development degree. Since the integrated territorial development is associated with significant cargo flows of raw materials, materials and goods, then logistics chains will include various transport types, which will lead to the construction and reconstruction of seaports, the network of railways and highways expansion. The scientifically grounded solution of problems of delivery route planning, selecting rolling stock, determining the location of transshipment points and logistics terminals will contribute to the sustainable development of the Arctic territories. The reasons and consequences of incorrect planning of supply chains are considered as an example. The article presents a problems tree has been built, which makes it possible to systematize risk situations, identify root causes and consequences. A method is proposed for calculating the time of delivery of goods, taking into account the multimodality of supply chains.

Keywords: arctic development, support zones, risks.

1. INTRODUCTION

The issues of sustainable territorial development acquire particular relevance in the 21st century, since the depletion of natural resources forces, along with the implementation of comprehensive strategies for their careful use, to search for their new sources. The new territories development is associated with a number of problems caused by their inevitable urbanization, disruption of ecosystems due to various activities types, which poses the greatest danger to the Arctic zone. In the Russian Arctic, a number of complex projects are being implemented, including the development of industrial economy's sectors and the tourism industry, which is possible only if transport corridors are created for the export of raw materials and goods delivery, as well as solving the problems of population mobility. These activities are accompanied by a variety of risks that can lead to serious consequences. To reduce possible damage, we must understand the risk situations causes, as well as possible ways to prevent them and minimize the likely consequences. The relevance of the integrated management of the Arctic marine environment based on the ecosystem approach is obvious. This is evidenced not only by the activities of the Arctic Council and its working groups, but also by broader international activities to implement the goals of sustainable development. Therefore, strategic planning and forecasting is important when developing development programs and infrastructure projects, taking into account risks and consequences in the short and long term [1-3].

The strategic vision for the Arctic zone development is determined both by its resource potential, which includes about 25% of the world's undiscovered mineral reserves, and by new opportunities for creating new transport and logistics corridors due to global climate change. A specific role in the implementation of projects for the Arctic development is played by the Northern Sea Route (NSR), which has great potential in the formation of international transport corridors (ITC) between Europe and Asia. However, despite the obvious advantages of water transport over its other types (low cost; large carrying capacity of sea vessels and their versatility), there are significant limitations: low speed of the goods delivery; the high cost of manufacturing ships and building specially equipped seaports; significant costs for the operation of ships and infrastructure (seaports, terminals, etc.); environmental problems associated with diesel emissions from ships, especially in coastal areas and port cities. All this requires a detailed study of development prospects, taking into account economic and environmental factors and risks.

2. TRANSPORT ROLE IN TERRITORIAL DEVELOPMENT

The high interest in the Arctic development is caused by geopolitical, economic and other factors. The uniqueness of the territories with rich natural and raw material resources is arousing growing interest both in the Arctic countries and in countries geographically distant from the Arctic. Efficient use of raw materials and logistic potential, biological and water resources, expansion of activities in shelf zones, development of fishing in traditional areas, etc. depends on the development of transport infrastructure, including ITC. Numerous scientific studies have been devoted to the role of transport in regional development.

2.1. Problems in the ITC formation

The study [4] purpose is to identify and formalize modern trends in the ITC construction and formation. The authors consider the systems of existing Euro-Asian transport corridors, regions of economic cooperation and agreements on international routes of various transport modes classification as international transport systems. The authors believe that the processes associated with the formation and development of international transport systems at the present stage require additional research, including to determine the feasibility and sustainability of their functioning.

The article [5] examines the current state and problems of the complex logistics systems development. The authors identified the main elements of the global logistics system in the implementation of various threats types that form cargo flows and proposed promising models and methods for an end-to-end scenario analysis of changes in international logistics flows along international transport corridors (including East to West), taking into account the restrictions (border, customs, sanitary, phytosanitary and others).

Since in interregional transportation land transport is an alternative to international sea shipping, several cross-border land corridor projects have been implemented. It should be borne in mind that although sea transportation is cheaper, it takes more time. The study [6] is aimed at identifying the factors that influence the choice of the transport mode for interregional cross-border transportation over long distances. The authors use the Tobit model to estimate the dependent variable, considering eight significant variables: distance, industrial exports, landlocked country / area, neighboring country / area, country risk, infrastructure level, port access time, and shipping frequency. The results obtained can facilitate the cross-border land corridor projects development to carefully consider factors affecting the optimization of land transport infrastructure through increased investment in paved roads and railways. A limitation of this study is that factors related to environmental impact were not considered.

The main goal of the article [7] is to determine the main technical and technological criteria affecting the traffic synchronization efficiency in the East-West Transport Corridor (EWTC) in the southern corridor part in the Baltic Sea Region (BSR). The study results showed that the main technical criteria affecting synchronization are: railway infrastructure and road transport infrastructure at the terminals. The most important criteria for technological interaction are the availability of seaports and railway distribution stations. According to the authors, future studies should use these factors to create models and facilitate synchronization in order to build an interconnected transport system covering all modes of transport.

The article [8] proposes to use a comprehensive analysis of transport logistics parameters when choosing an international route, for the goal of which a consulting logistics center is being formed. This will make it possible to identify profitable options for the use of vehicles or their combinations in the transport market and make high-quality logistics decisions on the rational international transportation route choice.

Since making decisions on the management of transport infrastructure is a complex task, it is necessary and important to assess its development, at least at the strategic level. The main article [9] goal is to determine and quantify the contribution of a transport infrastructure project to the economic system during its life cycle. A digital application is designed to evaluate a project to create a new freight transport corridor from the Black Sea to the Southeast Mediterranean, connecting the ports of Burgas (Bulgaria) and Alexandroupolis (Greece), for cross-border traffic that stimulates new business opportunities.

The article [10] presents a systematic approach, including theoretical and methodological aspects of the demand formation analysis for the use of the transport and logistics region infrastructure in the formation of the intelligent module of the regional transport and logistics information system (RTLIS). This system accumulates information about transport and logistics operations in the region or carried out through the region. According to the authors, this will make it possible to effectively use the transport and logistics region system, increase the efficiency of production enterprises activities and improve the transport services quality for the population.

The study [11] purpose is to analyze theblockchain technology possibilities and Industry 4.0 for moving supply chains towards sustainability. The authors use the existing literature for these purposes, considering three main areas: (1) energy management in smart enterprises using the Internet of Things (IoT); (2) smart logistics and transportation; and (3) smart business models. The authors conclude that although the blockchain is still developing and there are certain drawbacks, the opportunities that blockchain offers to increase sustainability can be applied in four directions: (1) development of incentive mechanisms and tokenization to encourage sustainable consumer behavior; (2) increasing the product life cycle transparency; (3) increasing the systems efficiency while reducing development and operating costs; and (4) promoting sustainability monitoring and reporting across all supply chain networks.

2.2. ITC Europe - Asia

China's Belt and Road Initiative (BRI) has become a central issue in international transport and global logistics since its inception, as infrastructure development and economic and transport corridors affect the interconnectedness of countries along the Belt and Road. Document [12] provides an overview of the logistics, supply chain and transport (LST) literature in the BRI context since 2013. containing 190 English articles on four main topics: (1) maritime and intermodal transport combined with MSR, (2) rail transport. in relation to sustainability, supply chain management and cross-border issues, (3) the role of infrastructure in economic and transport corridors, ports and railways for the development of trade and regional economies, and (4) energy supply chain development and carbon emissions.

The editorial [13] sets the context for a discussion of the great global convergence of world economies and the role of the Belt and Road Initiative in reconfiguring key global transport hubs and trade corridors. The importance of technological innovation and structural reforms is highlighted to help businesses manage the growing supply chain complexity and potential failures during the fourth industrial revolution in a sustainable way.

Central Asian countries are attracting investment in transport infrastructure to rehabilitate the Silk Road routes and reap economic benefits from participation in international trade. The work [14] is aimed at assessing how the transport corridor "Western Europe - Western China" (WE-WC) influenced the economic potential connecting cities and regions, from the transport infrastructure quality to their export potential. The study takes a modest step towards developing a culture of evidence-based decision-making in policymaking in Kazakhstan.

The analysis [15] results show that Russia can play the role of a transit country in the goods transportation from the Asia-Pacific region to Europe, receiving economic benefits from this, since there are a redistributing possibility existing and future volumes of container transit China-Europe through the border crossings Dostyk, Zabaikalsk and Zamyn-Uud. To realize these opportunities, it is necessary to solve a complex of legal, organizational and technical problems with the help of infrastructure solutions, as well as harmonization of international transport legislation in the field of freight traffic in the China-Europe transportation.

The article [16] proposes a methodology for assessing the regions economic potential affected by transport corridors, as part of the implementation of the Great Silk and Tea Road initiatives, based on the integral indicator calculation, which includes five indices: industrial, labor, food, innovation and financial. The methodology was tested in 28 regions of China, Mongolia, Russia and Kazakhstan in the context of five alternative transport corridors: three routes of the China-Mongolia-Russia economic corridor, the Western Europe-Western China corridor, and the Dostik-Ashankov-Mikhailovka-Uba corridor. According to the authors, the methodology makes it possible to assess the existing regions economic state, compare alternative options for the development of transport corridors, identify priority routes, as well as problematic points of regional development.

The work [17] goal is to formulate recommendations for improving the Russian national logistics system (NLS). The authors point out that the logistics development in the international market is important for any country. After analyzing Russian NLS using 6 dynamic indicators over 11 years, the authors derive recommendations for the its development, grouped into a priority list with 2 different resulting scenarios. According to the authors, it is necessary to separate measures, since the lack of resources may not allow to completely eliminate all identified bottlenecks in logistics at once.

2.3. ITC infrastructure and regional development

The article [18] examines the creation and functioning of multimodal transport and logistics hubs (Multihub), including possible options for their placement in promising "growth points", with the aim of including the Samara province in the new ITC Europe - America and the Arctic - Southwest Asia, which contributes to development of a multipolar multifunctional region structure. According to the authors, the transport infrastructure not only fixes the city's planning structure, but also determines its further development.

The article [19] analyzes the NSR potential as an ITC in terms of its economic and geopolitical factors in modern conditions, as well as the opportunities and threats of its activities. Based on the ITC characteristics analysis and the requirements for them of the participants in the international goods movement, the necessary conditions have been formulated that must be met by the ITC. The conclusion about the potential compliance of the NSR with the ITC requirements is based on the following: The NSR meets the requirements of the main transport line; it is linked to rail transport systems, and this link is developing; the icebreaker fleet and port infrastructure are being developed; security technical means are being created and modernized.

The focus of the authors [20] is the NSR of Russia, which is regarded as a transcontinental Eurasian maritime transport corridor. According to the authors, the NSR will be modernized, even if the Chinese idea of the "Polar Silk Road" is not implemented at all. Among the vulnerable areas of the Silk Road project implementation are harsh natural conditions, restrictions on the navigation season, insufficient capacity of the icebreaker fleet, economic sanctions from the United States and Western Europe, as well as the complexity of creating a modern transport infrastructure along the NSR.

The document [21] proposes an innovative forecasting methodology to estimate future transit volumes through a port in Iran using scenario planning, econometrics and heuristic calculations. The assessments take into account major transport corridors such as ITC North-South, Belt and Road Initiative, Suez Canal Route, TRACECA, Trans-Asian Railway, Central Asia Regional Economic Cooperation (CAREC) and Trans-Siberian Corridor. The proposed methodology is not tied to a specific country, so it can provide port authorities with valuable information that will help to cope with uncertainties in international trade and logistics in strategic planning.

2.3. ITC and green logistics

The paper [22] proposes a new quantitative model for assessing the of supply chains (SC) structure based on various manufacturing technologies, taking into account environmental and economic aspects, which identifies suitable KPIs for assessing SC in the context of additive and conventional manufacturing. The document is practical meaning: the model can help companies make decisions. The framework allows you to change the number of KPIs, and the relative weights can be updated. In the future, the model can be used to study the effect of additive technology on mixed production.

In [23], the problem of minimizing emissions by dissimilar vehicles in a heterogeneous road and transport network is considered. The procedure is based on an outlier-oriented elementary shortest path problem on a multigraph, which is solved using an inverse labeling algorithm. It is shown that the labeling algorithm can be accelerated by setting up a dual master program and limiting the number of labels in a subtask. Column generation method is used to set up fast heuristics, as well as the transition and price algorithm.

As part of the study [24], an ecological model of the SC and logistics was developed using network analysis. The best route for each significant case was the shortest route of the total distance from each recorded stop. The results show that the distribution center can help shorten the distance, leading to a reduction in greenhouse gas emissions.

The article [25] shows that the impact study of China's trade with the countries participating in the Belt and Road Initiative (BRI countries) is important for the “green” logistics development. Based on the findings, the corresponding policy implications are suggested. In addition, as a platform, not only will help these countries make a low-carbon transformation, but will also contribute to global environmental sustainability.

Foreign corporations have a dynamic potential to improve the environment in developing countries through green supply chain management (GSCM) practices and partnerships with governments and domestic firms to further reduce environmental impact. In this context, this article [26] has critically analyzed three strands of the GSCM literature that contributes to cleaner production, identifying the basic methods and driving forces for the adoption of GSCM to improve the environment in developing countries.

In the literature on road freight transport, more and more attention is paid to environmental aspects in order to reduce the logistics contribution to carbon dioxide emissions. The article [27] presents a systematic quantitative review of the literature on road freight transport decarbonization using bibliographic linkage and network analysis methods through systematic literary mapping. Despite its limitations, this study contributes to understanding the intellectual structure and emerging research areas of the literature on road freight transport decarbonization.

Article [28] discusses the new international land-sea trade corridor impact, jointly built by the western provinces of China and the ASEAN countries, on freight transport structures and proposes related proposals for the development of international logistics service providers. In connection with the strengthening of international economic cooperation and the rapid development of the global transport system, the corridor is seen as an important element in the regional economy development.

3. RESULTS AND DISCUSSIONS

The Arctic development is planned through a system of so-called "support zones" (SZ). In total, nine such zones have been created (Fig. 1), the task of which is to link all projects and resources located on their territory for the development of socio-economic activities, communication and resource potential in the Arctic zone (AZ) and to obtain the maximum synergistic effect. They will activate the transport capabilities of the NSR, meridional river and road corridors, air and rail links.

3.1. Support zones and their role in the Arctic development

Realizing their social role, the SZ work for the development of their region and the Russian AZ as a whole, ensuring an improvement in the quality of life of the population living and working here. From the point of view of the economic model, the use and investment projects implementation in the SZ provides for public-private partnership (PPP), among other mechanisms of state support. The SZ spatial structure is formed by the transport and industrial framework, the main elements of which are: 1) highways providing access to the NSR, communication with neighboring regions and SZ and transport accessibility of new sources of raw materials; 2) transport (ports, stations), mineral resources (extraction and primary processing of raw materials) and multifunctional nodes and centers (processing of resources, transshipment of goods, social and cultural sphere, energy, construction, etc.).

The basic difference between the emerging state program on the socio-economic development of Russian AZ is a new, comprehensive approach to the development of specific territories in the Arctic. A new mechanism for regional development (via SZ) was proposed by the Ministry of Economic Development of Russia in March 2016 based on the existing administrative-territorial division, resource base and functioning of transport hubs, including NSR.

1. Kola SZ. Advantages: favorable geographic location, year-round ice-free ports, mineral reserves, as well as a relatively developed transport, energy, industrial, scientific and educational infrastructure.
2. Karelian SZ - includes about 40% of the territory of the Republic of Karelia (these are 5 northern regions and the Kostomuksha city). Advantages: a common long border with Finland, a developed border and road infrastructure, the formation of all-Russian corridors on the territory of the Republic of Karelia.
3. The Arkhangelsk SZ is characterized by an advantageous geographical position associated with a well-developed railway infrastructure and a year-round port (November - March only for ice-class ships or with icebreaker assistance).
4. The Nenets SZ includes a number of promising areas of economic development, primarily related to the development of the NSR and mining.
5. The Vorkuta SZ includes the municipal formation of the urban district "Vorkuta" (MO GO Vorkuta) of the Komi Republic.
6. The Yamalo-Nenets SZ is one of the most promising and is capable of providing a stable cargo flow to the NSR sea ports.

7. The Taimyr-Turukhansk SZ on the territory of the Krasnoyarsk Region has a resource extraction and industrial focus. It includes a large agglomeration in the Arctic - the Norilsk industrial region (centered in the city of Norilsk).
8. North Yakutsk SZ in the Republic of Sakha (Yakutia), the center of which is one of the key points of the NSR eastern part - the Tiksi port.
9. Chukotka SZ - on its territory there is a number of transport infrastructure objects that are backbone for the Chukotka Autonomous Okrug, which can become the main points of growth in the NSR eastern sector and the Russian AZ.

The formation of "support zones for the Arctic development" provides an approach to the territory development as an integral project on the principle of ensuring the interconnection of all "sectoral" activities at the stages of planning, goal setting, financing and implementation, which will reduce all types of costs and expenses. The support zones orientation to the Northern Sea Route seaports will make it possible to intensify the activities of shipbuilding and ship repair enterprises both in the Arctic zone and in other Russian Federation constituent entities.

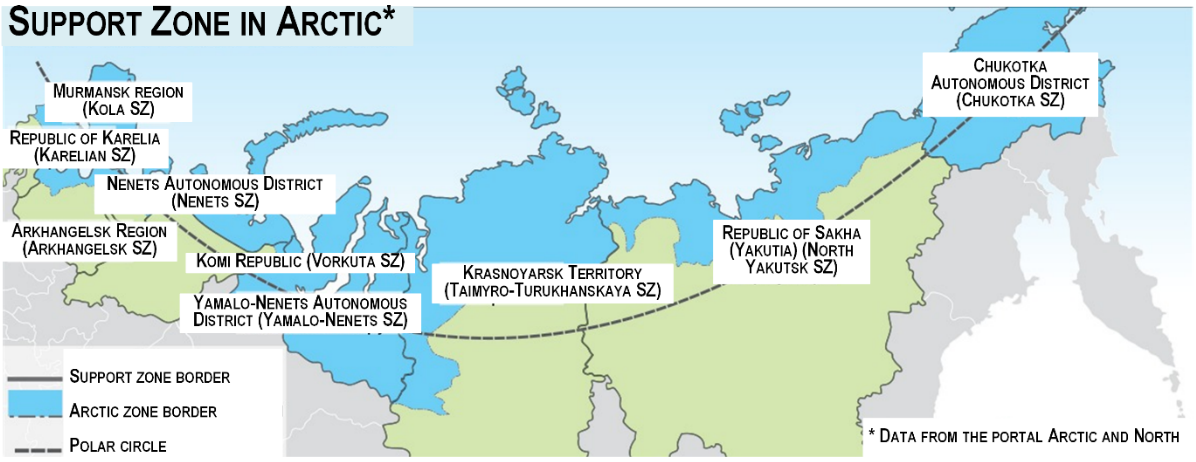


Figure 1 Support zones in Arctic

The closely interconnected complex resource and (especially) infrastructural directions determine the development prospects, which depend on the characteristics of the transport framework, in accordance with the development of which, the SZ can be clustered as follows: zones with a developing framework: Arkhangelsk, Kola, Karelian; zones with an emerging framework: Yamalo-Nenets and North-Yakutsk; zones with a projected frame: Nenets and Vorkuta; zones where reconstruction and formation of a frame is required: Taimyro-Turukhanskaya and Chukotskaya. Based on this, goals are formulated to ensure: development of the transport network at the expense of all types of transport (for the Arkhangelsk, Karelian and Kola zones); railway exit to the ports of the NSR (for the Nenets and Vorkuta zones); strengthening of the main transport axis "road - sea" or "river - sea" with the reconstruction of ports on the NSR (for other zones).

3.1.1. Mineral resource centers

The Yamalo-Nenets SZ will be based on the oil and gas chemical cluster. Already, more than 80% of Russian gas is produced at the Okrug's fields, which is one fifth of the world production. Due to the projected depletion of the continental subsoil, it is planned that the prospect will be production in the north of the Yamal Peninsula, on the shelf of the Obskaya and Tazovskaya bays of the Kara Sea, which will be able to compensate for the falling volumes of such fields as Urengoyskoye, Medvezhye, Vyngapurskoye and Yamburgskoye. New gas production areas will provide more than a third of gas production in the country, which will allow the development of the eastern export direction and the new terminals for the liquefied gas production construction in the Arctic.

The development of the Kola SZ is associated with the wealth of the Murmansk region in minerals. To develop this potential, the program envisages supplying the region with qualified personnel through local educational institutions, including the recently established Center for Arctic Competencies and Murmansk State Arctic University. The program includes investments in the Kola SZ educational infrastructure development and the attraction of about 2 thousand high and medium-level specialists from other Russian regions.

The main economy sectors that will ensure the Arkhangelsk SZ development will be shipbuilding, mechanical engineering, logistics, timber industry and tourism. In addition, it is planned to develop new areas, such as the extraction of lead, zinc and silver. Also, the Arkhangelsk Region will focus on the transport infrastructure development in order to provide a full-fledged corridor for the Arctic development.

The Taimyr-Turukhansk SZ formation is expected on the territory of the Taimyr, Turukhansk districts of the Krasnoyarsk Territory and Norilsk. The Norilsk Nickel company is already operating on this territory. The company's Polar Division produces more than 90% of the Russian volume of nickel, more than 40% of copper, 98% of platinum group metals. The company plans to implement projects to expand the ore base. In addition, the development of the Norilsk Metallurgical Center can be supported by the development of deposits of platinum group metals "Chernogorsk" and "Norilsk-1" (southern part) by the company "Russian Platinum", as well as the development of the Maslovskoye deposit. Also, within the framework of the project for the creation of the Taimyr-Turukhansk SZ, it is planned to develop coal deposits. The Severnaya Zvezda company plans to build an open pit, an enrichment plant, a thermal power plant and a 120-kilometer branch line to the Dikson settlement on the Syradasay prospective area. The Vostok Ugol management company, which has licenses for the geological study of coal in the Taimyr coal-bearing basin, plans to export it to Western Europe and the Asia-Pacific region. For this, the possibility of building a coal terminal in the Dikson port in the area of Cape Chaika with a cargo turnover of 10 million tons of coal per year is being considered. It is planned to create new centers for hydrocarbon production. In the SZ, the subsoil structure of the companies Lukoil and Rosneft is being studied.

3.1.2. Transport infrastructure

The formation of the North Yakutsk SZ is a pilot project; its experience is subsequently planned to be extended to the entire territory of the Arctic zone. The emphasis will be placed on the development of transport infrastructure. It is mostly water and is formed around the NSR and navigable rivers of the Lena basin. Reconstruction of ports, creation of a high-tech Zhatayskaya shipyard, construction of river vessels of various types and purposes, as well as construction of "river-sea" class vessels are envisaged. In addition, it is planned to reconstruct regional and local airports (Chersky, Chokurdakh, Tiksi, Deputatsky).

The creation of a transport infrastructure based on a unified system of the NSR, air traffic and highways is also important for the Chukotka SZ. To increase the transport accessibility of this region, it is necessary to reconstruct the airports of regional and local significance: the Bay of the Cross, Keperveem and Beringovsky. Air transport is the only main mode of transport that connects these settlements with the rest of Russia.

3.1.3. Development of the shelf

In the Nenets Autonomous Okrug, the stake will be placed on the continental shelf development. It is planned that by 2020 the production of oil and gas in the region will grow to 32-35 million tons of oil equivalent, the growth of industrial production in 2030 compared to 2007 will increase by 2.5 times, the real income of the population will increase by 3.5 times. However, in order to achieve these indicators, the region will have to eliminate the discrepancy between the scale of industrial projects unfolding here and the development of new deposits on the Arctic shelf. For this, several large projects for the construction of new transport routes and the development of port infrastructure will be implemented in the NAO at once.

The Komi SZ includes the municipality of the urban district "Vorkuta". Today it is a single-industry town and the largest coal mining center in the Pechora coal basin. It is expected that the activities of the Vorkuta support zone can contribute to an increase in coal production to 21.4 million tons per year.

3.2. Risk management of transport and logistics processes

Since a transport framework is being created to implement the Arctic zone development strategy, the logistic chains will include different transport modes [29-32]. In this case, the cargo delivery total time can be estimated as follows:

$$T=\sum_{w=1}^{4}\sum_{i\in A_w} t_i+\sum_{w=1}^{4}\sum_{j\in B_w} y_j+\sum_{w=1}^{4}\sum_{k\in C_w} s_k+\sum_{w=1}^{4}\sum_{l\in D_w} r_l+\sum_{m=1}^{E} v_m+\sum_{n=1}^{F} z_n+\sum_{w=1}^{4}\sum_{p=1}^{4}\sum_{o\in G_{w,p}} x_o \qquad (1)$$

w,p ={1– automobile transport, 2–water transport, 3–railway transport, 4–air transport}, $w \neq p$;

t_i – travel time on the i-th section by w-mode of transport;

y_j – time of customs documents registration at the j-th point;

s_k – time of loading, unloading and storage at the k-th point;

A_w, B_w, C_w – a set of traffic sections, customs clearance and loading-unloading points by w-mode of transport respectively;

r – duration of rolling stock and infrastructure facilities unplanned repair;

D_w – the number of the w-transport's downtime, considering unplanned repair;

v – the duration of downtime associated with the drivers' work and rest regime;

z – the duration of downtime or an increase in the movement time associated with bans on heavy vehicles movement;

E, *F* – the number of vehicle downtime, considering the above reasons, respectively;

x_o – transshipment time at o-th point from w-th to p-th mode of transport;

$G_{w,p}$ – a set of points of transshipment from the w-th to the p-th mode of transport;

At the same time, the risks that characterize each transport type should be additionally taken into account. Evaluating the route efficiency can also include price indicators and other factors.

The creation and development of infrastructure and supply chains is inevitably associated with potential risks: environmental, social and economic, the occurrence of which is due to errors in the planning and implementation of the development strategy. The tree method is widely used to assess the likelihood of such problems occurring. Particular attention should be paid to the problem of infrastructure underdevelopment and imperfection, since there is a high risk of developing anthropogenic disasters. Therefore, we built a tree that helps to analyze various situations, highlighted the root causes and consequences (Fig.2).

The complex risk of event G is estimated as the sum of basic events and can be calculated using the formula:

$$Q(G)=\sum_{k=1}^{n} q(x_k)=\sum_{k=1}^{n}\sum_{j=1}^{m_k} q(x_{kj})=\sum_{k=1}^{n}\sum_{j=1}^{m_k}\sum_{p=1}^{r_{kj}} q(x_{kjp}) \qquad (2)$$

where *Q* is the probability of the upper event (namely, the event *G*); *n* – the number of child events of event G; m_k, r_{kj} – the number of child events for events x_k, x_{kj}; $q(x_k)$, $q(x_{kj})$, $q(x_{kjp})$ – the probabilities of events

x_k, x_{kj}, x_{kjp} of the first, second and third levels, respectively. The probability of the base events $q(x_{kjp})$ can be estimated by a statistical analysis of historical data on the operation.

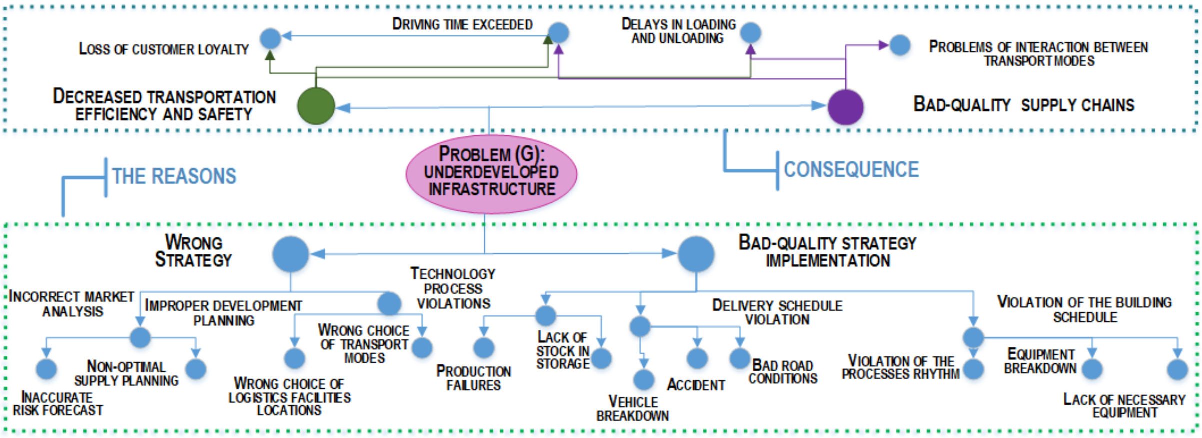


Figure 2 Problem tree to streamline the causes and consequences of the underdeveloped NSR infrastructure

4. CONCLUSION

Climate change opens up wide opportunities for the development of the Russian Arctic, including the NSR. Significant reserves of minerals, convenient access to the sea for the transportation of crude oil, liquefied natural gas and other resources make this region promising and energetically important. This investment area is a priority for Russia and may have a positive effect. The development of the Arctic is planned through a system of so-called "support zones", for the creation and development of which projects are being implemented with the active participation of the state. Such zones differ in the degree of development: there are zones with a developed transport framework, with a formed socio-economic system (Kola, Karelian, Arkhangelsk), and there are those where the transport framework is just being formed, and various areas of activity are actively developing, since the territories have significant potential growth (for example, Yamalo-Nenets). Sustainable development is possible only with the implementation of complex projects in which transport infrastructure is an important component. Since the integrated territorial development is associated with significant cargo flows of raw materials, materials and goods, the logistics chains will include various types of transport, which will lead to the construction and reconstruction of seaports, the expansion of the network of railways and highways. When forming a development strategy, one should take into account transport risks that may upset the balance in the developed area. The scientifically grounded solution of building a delivery route problem, selecting rolling stock, determining the location of transshipment points and logistics terminals will contribute to the sustainable development of the Arctic territories. The reasons and consequences of incorrect planning of supply chains are considered as an example. A problems tree has been built, which makes it possible to systematize risk situations, identify root causes and consequences. A formula for calculating the complex risk has been introduced. A method is proposed for calculating the time of delivery of goods, considering the multimodality of supply chains.

REFERENCES

[1] Makarova, I. et al.: Urban transport system management in the context of region sustainable development strategy, Transport Problems, 2013, Vol. 8, No 2, pp. 107-111, (ISSN 1896-0596).

[2] Makarova, I. et al.: Development of sustainable transport in smart cities, 2017 IEEE 3rd International Forum on Research and Technologies for Society and Industry, 2017, pp. 1-6, DOI: 10.1109/RTSI.2017.8065922.

[3] Pernebekov, S.S. et al.: Modeling of traffic flows with due regard to ecological criteria, Life Science, 2014, Vol. 11, No 5, pp. 300-302, (ISSN: 0024-3205).

[4] Baginova, V., Zenkin, A., Ushakov, D.: Current trends in the formation of international transport systems, E3S Web of Conferences, 2020, Vol. 175, Article No.14014, (ISSN: 2267-1242), DOI: 10.1051/e3sconf/202017514014

[5] Ismailov, Z. I., Kononov, D. A., Ponomarev N. O.: Scenario Analysis of Development of Complex Logistics Systems, 2020 13th International Conference Management of large-scale system development, Moscow, Russia, 2020, pp. 1-5, doi: 10.1109/MLSD49919.2020.9247774.

[6] Hanaoka, S., Matsuda, T., Saito, W., Kawasaki, T., Hiraide, T.: Identifying Factors for Selecting Land over Maritime in Inter-Regional Cross-Border Transport, Sustainability, 2021, Vol. 13, No 3, Article No. 1471, (ISSN: 2071-1050), DOI: 10.3390/su13031471.

[7] Batarlienė, N., Šakalys, R.: Criteria Impacting Synchronization of Transport Flows along International Transport Corridor, Promet - Traffic&Transportation, 2020, Vol. 32 No 3, pp. 399-08, (ISSN: 1848-4069), DOI: 10.7307/ptt.v32i3.3322.

[8] Selivanov, A. V., Belyakova E. V., Ryzhaya A. A.: The route selection of international traffic flows of the machine-building enterprise, IOP Publishing Ltd Journal of Physics: Conference Series, 2019, Vol. 1399, No 3, Article No. 033053, (ISSN: 1742-6596), DOI: 10.1088/1742-6596/1399/3/033053.

[9] Dimitriou, D., Sartzetaki, M.: Assessment framework to develop and manage regional intermodal transport networks, Research in Transportation Business & Management, 2020, Vol. 35, Article No. 100455, (ISSN 2210-5395), DOI: 10.1016/j.rtbm.2020.100455.

[10] Lyapin. S., Rizaeva Y., Kadasev. D., Sysoev A.: Methods to Analyze Traffic Demand Formation in Intelligent Transportation and Logistic Regional Network, Transportation Research Procedia, 2020, Vol. 45, pp. 522-529, (ISSN 2352-1465), DOI: 10.1016/j.trpro.2020.03.061.

[11] Esmaeilian, B., Sarkis, J., Lewis, K., Behdad, S.: Blockchain for the future of sustainable supply chain management in Industry 4.0, Resources, Conservation and Recycling, 2020, Vol. 163, Article No. 105064, (ISSN 0921-3449), DOI: 10.1016/j.resconrec.2020.105064.

[12] Wei, H., Lee, P. T.-W.: Designing a coordinated horizontal alliance system for China's inland ports with China railway express platforms along the Silk Road Economic Belt, Transportation Research Part E: Logistics and Transportation Review, 2021, Vol. 147, Article No. 102238, (ISSN: 1366-5545), DOI: 10.1016/j.tre.2021.102238.

[13] Chhetri, P., Gekara, V., S. Li, Lee, J. Y.: Changing global production network and its implication on Belt and Road Initiative, Journal of International Logistics and Trade, 2020, Vol. 18, No. 1, pp. 13–14, (ISSN: 2508-7592), DOI: 10.24006/jilt.2020.18.1.013.

[14] Taisarinova, A., Loprencipe, G., Junussova, M.: The Evolution of the Kazakhstani Silk Road Section from a Transport into a Logistics Corridor and the Economic Sustainability of Regional Development in Central Asia, Sustainability, 2020, Vol. 12, No 15, Article No. 6291, (ISSN: 2071-1050), DOI: 10.3390/su12156291.

[15] Stepanova, N. et al.: Development of rail freight from China to the EU: Russia's opportunities, IOP Conference Series: Earth and Environmental Science, 2019, Vol. 403, Article No. 012216, (ISSN: 1755-1315), DOI: 10.1088/1755-1315/403/1/012216.

[16] Lubsanova, N., Mikheeva, A.: Comparative assessment of the potential of the regions of the zone of influence of the Great Silk and Tea Road, WSEAS TRANSACTIONS on BUSINESS and ECONOMICS, 2020, Vol. 17, pp. 638-645, (ISSN: 2224-2899), DOI: 10.37394/23207.2020.17.61.

[17] Beysenbaev, R., Dus, Y.: Russia's national logistics system: main directions of development, LogForum 2020, Vol.16, No 2, pp. 209-218, (ISSN:1734-459X), DOI: 10.17270/J.LOG.2020.395.

[18] Gud, I. D.: Multihub – point of increase in Samara agglomeration- conurbation spatial development, IOP Conference Series: Materials Science and Engineering, 2020, Vol. 775, Article No. 012018, (ISSN: 1757-899X), DOI: 10.1088/1757-899X/775/1/012018.

[19] Skripnuk, D. F. et al.: The Northern Sea Route: Is There Any Chance to Become the International Transport Corridor, IOP Conference Series: Earth and Environmental Science, 2020, Vol. 434, Article No. 012016, (ISSN: 1755-1315), DOI:10.1088/1755-1315/434/1/012016.

[20] Gladkiy, Yu. N. et al.: Polar Silk road: project implementation and geo-economic interests of Russia and China, IOP Conference Series: Earth and Environmental Science, 2020, Vol. 434, Article No. 012009, (ISSN: 1755-1315), DOI:10.1088/1755-1315/434/1/012009.

[21] Ghasemi, A., Miandoabchi, E., Soroushnia, S.: The attractiveness of seaport-based transport corridors: an integrated approach based on scenario planning and gravity models, Marit Econ Logist, 2020, (ISSN: 1479-294X), DOI: 10.1057/s41278-020-00175-2.

[22] Rinaldi, M., Caterino, M., Fera, M., Manco, P., Macchiaroli, R.: Technology selection in green supply chains - the effects of additive and traditional manufacturing, Journal of Cleaner Production, 2021, Vol. 282, Article No. 124554, (ISSN 0959-6526), DOI: 10.1016/j.jclepro.2020.124554.

[23] Behnke, M., Kirschstein, T., Bierwirth, C.: A column generation approach for an emission-oriented vehicle routing problem on a multigraph, European Journal of Operational Research, 2021, Vol. 288, No 3, pp. 794-809, (ISSN 0377-2217), DOI: 10.1016/j.ejor.2020.06.035.

[24] Yachai, K., Kongboon, R., Gheewala, S.H., Sampattagul, S.: Carbon footprint adaptation on green supply chain and logistics of papaya in Yasothon Province using geographic information system, Journal of Cleaner Production, 2021, Vol. 281, Article No. 125214, (ISSN 0959-6526), DOI: 10.1016/j.jclepro.2020.125214.

[25] Wang, Y., Xin, L.: The impact of China's trade with economies participating in the Belt and Road Initiative on the ecological total factor energy efficiency of China's logistics industry, Journal of Cleaner Production, 2020, Vol. 276, Article No. 124196, (ISSN 0959-6526), DOI: 10.1016/j.jclepro.2020.124196.

[26] Asif, M.S., Lau, H., Nakandala, D., Fan, Y., Hurriyet, H.: Adoption of green supply chain management practices through collaboration approach in developing countries – From literature review to conceptual framework, Journal of Cleaner Production, 2020, Vol. 276, Article No. 124191, (ISSN 0959-6526), DOI: 10.1016/j.jclepro.2020.124191.

[27] Meyer, T.: Decarbonizing road freight transportation – A bibliometric and network analysis, Transportation Research Part D: Transport and Environment, 2020, Vol. 89, Article No. 102619, (ISSN 1361-9209), DOI: 10.1016/j.trd.2020.102619.

[28] Jiang, Y., Qiao, G., Lu J.: Impacts of the New International Land–Sea Trade Corridor on the Freight Transport Structure in China, Central Asia, the ASEAN countries and the EU, Research in Transportation Business & Management, 2020, Vol. 35, Article No. 100419, (ISSN 2210-5395), DOI: 10.1016/j.rtbm.2019.100419.

[29] Almetova, Z. V., Shepelev, V. D., Kuznetsov, N. A.: The integrative process of transport systems of the eurasian economic union, IOP Conference Series: Earth and Environmental Science, 2019, Vol. 272, No 2, Article No. 022234, (ISSN 1755-1315), DOI: 10.1088/1755-1315/272/2/022234.

[30] Shepelev, V., Zverev, L., Almetova, Z., Shubenkova, K., Shepeleva, E.: Optimization of interaction of automobile and railway transport at container terminals, Selected Papers from the 18th International Conference on Reliability and Statistics in Transportation and Communication, Riga, Latvia, 2018,pp. 593–602, (ISBN 978-3-030-12450-2), DOİ: 10.1007/978-3-030-12450-2_57.

[31] Galkın, A.: Mechanisms for increasing of transportation efficiency using joint service of logistics systems, Archives of Transport, 2019, Vol. 49, No. 1, pp. 7-24, (ISSN 0866-9546), DOI: 10.5604/01.3001.0013.2770.

[32] Kush, Y., Skrypin, V., Galkin, A., Dolia, K., Tkachenko, I., Davidich, N.: Regularities of Change of The Supply Chain Operation Efficiency, Depending on The Parameters of The Transport Process, Transportation research procedia, 2018, Vol. 30, pp. 216-225, (ISSN 2352-1465), DOI:10.1016/j.trpro.2018.09.024.

EXHAUST EMISSIONS FROM MARINE 4-STROKE ENGINE ON THE THREE FUEL TYPES

Siniša Martinić-Cezar

Karlo Bratić
Pomorski fakultet u Splitu, Sveučilište u Splitu
Split, Croatia
E-mail: kbratic@pfst.hr

Merica Slišković
Pomorski fakultet u Splitu, Sveučilište u Splitu
Split, Croatia
E-mail: merica.sliskovic@pfst.hr

Nikola Račić
Pomorski fakultet u Splitu, Sveučilište u Splitu
Split, Croatia
E-mail: nikola.racic@pfst.hr

UDK 504.5:621.43.068

Summary

Exhaust emissions from ships are the focus of environmental protection today. The combustion of fossil fuels produces various exhaust gasses, but the most important are sulfur oxides, nitrogen oxides and the greenhouse gas carbon dioxide. The aim of this paper is to compare the three fuel types used for propulsion in DFDE engines (MAN -B&W, type: 8L51/60DF), to describe their main characteristics and to list the advantages and disadvantages of their use in terms of economy and environmental friendliness. The focus is on nitrogen oxides and the greenhouse gas carbon dioxide, which are produced during the combustion of marine diesel engines. Specific fuel oil consumption is also considered as a function of engine load and mode of operation. The first part of the paper describes the formation of NOx and CO2 in the combustion process of marine engines and their impact on the environment. The main provisions of MARPOL (Annex VI) are also given. The second part of this paper brings a series of measurements on the ship simulator (5000 TechSim Dual Fuel Diesel-Electric LNG Carrier, version 8.8) of exhaust emissions at three different fuel types (Marine Diesel Oil, Heavy Fuel Oil and Liquefied Natural Gasses) at different engine loads were performed and the obtained data were graphically presented in the diagram and compared with the data from a test-bed of the same engine type.

Keywords: Dual fuel diesel engine, gas emission, nitrogen oxid, carbon dioxid, simulator

1. INTRODUCTION

The global trend is towards environmental protection, so exhaust emissions from ships certainly take their place. Air emissions include pollutants and greenhouse gasses. The main focus of this paper is on the main pollutants: NOx, and the greenhouse gas CO_2.

Nowadays, liquefied natural gas (LNG) is increasingly used to power marine engines. Unfortunately, it has negative effects on the environment and human health.

This study focuses on the investigation of a four-stroke DFDE marine DFDE engine to compare its emissions of the main pollutants NOx and the greenhouse gas CO2, considering the specific fuel oil consumption (SFOC). In addition, the injection of three different fuels into the engine cylinders is considered: Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO) and Liquefied Natural Gas (LNG) with the amount of pilot diesel fuel. The derived results were analyzed to show the differences of engine fuel oil consumption, NOX, and CO2 emissions in each mode.

Measurements were performed on the ship simulator for liquefied natural gas and conventional fuels (HFO and MDO) at different loads, and the obtained data were compared with the actual results from the test-bed aiming to identify the engine settings that simultaneously reduce CO2 and NOx emissions considering SFOC. The results are discussed to derive the optimum engine settings.

Many works have analyzed the emissions of propulsion systems at variable speeds [7, 8], but no comparison and accuracy of marine engine exhaust emissions data from simulators has been published in the available literature.

2. FORMATION OF NOx IN DIESEL ENGINE AND ENVIRONMENTAL IMPLICATIONS

NOx as the sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2) is produced during combustion, in an oxidation reaction between atmospheric nitrogen (N_2) and oxygen (O_2). [1]

The combination of high temperatures, the availability of oxygen and nitrogen, and the duration of combustion in the diesel engine are the key elements on which NOx production depends. When combustion temperatures are higher, NOx production is higher because it depends on the combustion temperature. Because of the dependence on the amount of oxygen on the lean side of the stoichiometric conditions, the highest NOx occurs. [1] Thermal, prompt, and nitrous oxide formation are the mechanisms associated with the formation of NOx. [1]

Based on the Zeldovich mechanism, the **formation of nitric oxide** can be described by the following reactions [2]:

$$N2 + O \rightarrow NO + N$$

$$N + O2 \rightarrow NO + O$$

$$N + OH \rightarrow NO + H$$

Temperature plays an important role in the formation NO, i.e. below 1700 the rate of formation is insignificant, while at temperatures above 2000K the rate of formation increases. Based on this, with lower and controlled temperature peaks and minimizing the exhaust gas residence at high temperatures, the formation of thermal NO can be reduced. [2]

The following equation represent total formation rate of ***thermal nitrogen oxides*** [2]:

$$\frac{d[NO_x]}{dt} = \frac{6 \cdot 10^{16}}{T^{0,5}} \cdot e^{\left(\frac{-69090}{T}\right)} \cdot [N_2] \cdot [O_2]^{0,5}$$

where T is absolute flame temperature (K), N_2 nitrogen molecule concentration (molcm^{-3}), O_2 oxygen molecule concentration (molcm^{-3}) and dNOx / dt nitrogen oxide speed formation (molcm^{-3}). [2]

Prompt nitric oxide can be formed promptly at the flame front by the presence of hydrocarbon radicals produced only at the flame front at relatively low temperature. Nitric oxide generated via this route is named 'prompt nitric oxide (NO)'. Hydrocarbon (HC) radicals react with nitrogen molecules with the following sequence of reaction steps:

$$CH + N_2 \rightarrow HCN + N$$

$$HCN + N \rightarrow \cdots \rightarrow NO$$

Nitrogen reacts with an HC radical to produce hydrogen cyanide HCN, and further, HCN reacts with nitrogen to produce nitric oxide via a series of intermediate steps. In contrast to thermal NO mechanisms that have activation temperature above 1700 K from (160), prompt NO can be formed starting at low temperature, around 1000 K. [2]

Although NOx can be of both natural and anthropogenic origin, fossil fuel combustion is the largest source of anthropogenic NOx. The various negative environmental impacts, such as eutrophication, acidification, and formation of ground-level ozone, as well as climate impacts, can be linked to NOx emissions. As additional effects of eutrophication caused by dry and wet nitrate inputs, water quality may deteriorate, and biodiversity may decline. Furthermore, excessive primary production can lead to a hypoxic and anoxic state of the water.[1]

2.1. NOx Regulations for merchant ships

The Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines was adopted on 1997 by MARPOL 73/78. According to the MARPOL 73/78 Annex VI Regulations for the Prevention of Air Pollution from Ships, each marine diesel engine to which regulation 13 of that annex applies, must comply with the provisions of this Code. Marine Environmental Committee has made several revisions to MARPOL Annex VI and NOx Technical Code 2008 (Resolution MEPC.177(58), as amended by Resolution MEPC.251.(66)). [3, 4]

This Technical code specifies the requirements for the testing, survey, and certification of marine diesel engines to comply with the emission limitations regulated in Annex VI. Regulation 13 applies to diesel engines of an output exceeding 130 kW installed in a ship which was constructed on or after 1 January 2000 or which undergoes a major conversion after 1 January 2000, but does not apply to emergency diesel engines, engines installed in lifeboats and any appliances or equipment intended solely for emergency use. [3, 4]

An Engine International Air Pollution Prevention (EIAPP) Certificate is issued to ships to control NOx emissions from diesel engines through survey and certification requirements. [3]

Depending on the construction date of the ships, different NOx emission values are applied (Table 1.)

Upon entering into the force, Tier 2 globally replaces Tier 1. While Tier 2 reduces emission levels by 20% compared to Tier 1, Tier 3 reduces emission levels by 80% compared to Tier 1. [4]

Table 1 NOx Tiers [3]

Tier	Entered into force	Ships construction date (on or after)	Total weighted NOx emission limit value (g/kWh) *n = engine's rated speed / crankshaft revolutions per minute (rpm)*		
			n < 130	n = 130 - 1999	n ≥ 2000
I	2005	1 January 2000 and prior to 1 January 2011	**17.0**	$45 \cdot n^{-0.2}$	**9.8**
II	1 January 2011	1 January 2011	**14.4**	$44 \cdot n^{-0.23}$	**7.7**
III	2016	1 January 2016* 1 January 2021**	**3.4**	$9 \cdot n^{-0.2}$	**2.0**

*ships operating in North American or the US Caribbean ECA **ships operating in the Baltic Sea or the North Sea ECA

Source: [3]

3. CARBON DIOXIDE (CO_2) IN DIESEL ENGINE AND ENVIRONMENTAL IMPLICATIONS

CO_2 as a result of the combustion of carbon (C) and oxygen (O_2) in diesel engines has been linked to the "greenhouse effect" and global warming. The concentration of CO_2 depends on the type of fuel, more specifically the content of carbon, hydrogen and other combustible components. The maximum concentration is reached when the full amount of fuel reacts with oxygen from the air during combustion, i.e. stoichiometric combustion. [1]

Table 2. gives the maximum carbon dioxide values of exhaust gases for common marine fuels. [2]

Table 2. Maximum CO_2 values for marine fuels, assuming the gases are dry [2].

Fuel	CO_2 max (%)
Natural gas	11.9
Light fuel oil	15.5
Heavy fuel oil	15.8

Source: [2]

The following expression can be used to calculate the maximum value of CO_2 [2]:

$$CO_2\max = \frac{\text{No. of } CO_2 \text{ molecules produced by complete combustion of fuel}}{\text{Total no. of molecules of combustion products}}$$

For 'wet' exhaust gases:

$$CO_2\max = \frac{c}{c + \frac{h}{2} + \frac{79,1}{20,9}\cdot\left(c + \frac{h}{4}\right)}\ \%,$$

For 'dry' exhaust gases:

$$CO_2\max = \frac{c}{c + \frac{79,1}{20,9}\cdot\left(c + \frac{h}{4}\right)}\ \%$$

If the oxygen concentration, the maximum concentration of carbon dioxide and the fuel type are known, the CO_2 concentration in the exhaust emissions can be calculated using the following expression [2]:

$$[CO_2] = \frac{CO_2\max\cdot\left(20,9 - [O_2]\right)}{20,9}.$$

Since the amount of CO2 emitted is directly proportional to the amount of fuel consumed and energy efficiency, a reduction in its emission can be achieved by reducing SFOC. Also, using the expensive fuel with a low carbon-to-hydrogen ratio can be a good way to reduce CO2 emissions. [2]

3.1. CO_2 regulations for merchant ships

According to the IMO Fourth GHG Study 2020, 2.89% of total global CO2 emissions for 2018 can be associated with shipping. [10] Given the international complexity of shipping, this emission cannot be attributed to any specific economy. In 2011, the MEPC added a new chapter to the Annex VI to address the issue of greenhouse gas emissions from ships.

The aim of this chapter is to improve the energy efficiency of ships and thus CO2 emissions through mandatory, cost-effective, operational and technical measures for different types of ships. This is the first mandatory legislative measure to minimize CO2 emissions from ships. Chapter 4 has been amended over the years and one of the latest amendments in 2018 introduced new regulation 22A on the collection and reporting of Ship Fuel Oil Consumption Data. Regulation 22A requires all vessels of 5,000 GT or more to collect consumption data for each type of fuel oil they use. [5]

In 2019, MEPC 74 proposes further improvement of the existing regime, strengthens cooperation with ports and approves an impact assessment procedure for newly proposed measures. [5]

4. THE SHIP SIMULATOR MEASUREMENT RESULTS

One of the goals in this paper is to record the data on the simulator and compare them with those measured on the test - bed at the same loads and with the same fuels. After the analysis, the validity of the data on the simulator will be evaluated.

Exhaust gas data will be recorded: as NOx, CO_2 and SFOC as well, on the ship simulator (5000 TechSim Dual Fuel Diesel-Electric LNG Carrier, version 8.8).

Simulator - Ship general characteristics:

- Length: 299.9 meters.
- Breadth: 45.8 meters.
- Design draft: 11.5 meters.
- Speed service approx.: 19.5 knots.
- Cargo Tank capacity: 170,200 m3.

Simulator – Engines general characteristics:

- Manufacturer: MAN B&W
- Type: 8L51/60DF
- Type: Four-stroke, in-line, dual fuel, turbocharged
- Rated power: 8,000kW (MCR) on LNG, 8,000kW(MCR) on MDO
- Speed: 514 rpm
- Cylinder bore: 510mm
- Piston stroke: 600mm
- No.of cylinders: 8

Measurements were made on three different types of propulsion fuel:

- HFO - Heavy fuel oil
- MDO - Marine diesel oil and
- LNG – Liquefied natural gases

Measurements were performed on engine loads of:

- 20% load (1557 kW)
- 40% load (3055 kW)
- 50% load (3857 kW)
- 75% load (5793 kW)
- 85% load (6563 kW)

4.1. NOx emissions on different fuels considering engine load

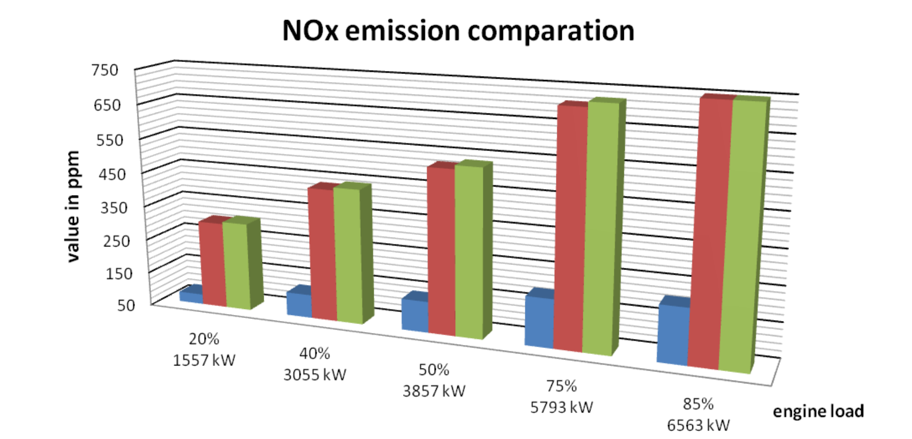
Diagram 1 shows the NOx (ppm) emissions at various engine loads and when running the engine on three types of fuel (HFO, MDO and LNG) recorded on the simulator.

As shown on diagram - NOx emissions are lower at lower engine loads and increase in line with engine loads for all three fuel types.

There are noticeable differences when the engine runs on LNG, NOx emissions are significantly lower compared to when the engine runs on liquid fuels (HFO and MDO). Also it can be noticed that it increases slightly in relation to the engine load.

NOx emissions during engine operation on HFO and MDO are slightly increased at all loads when using HFO compared to MDO, and this ratio is constant.

When HFO is used the nitric oxide (NO) formation is important. Due to the fact that HFO contains up to 0,5% of nitrogen, which is more than in MDO and other distillate fuels, the NOx emission can increase for 10%. [2]



Engine load	20% 1557 kW	40% 3055 kW	50% 3857 kW	75% 5793 kW	85% 6563 kW
NOx (GAS) (ppm)	79	118	140	190	209
NOx (MDO) (ppm)	303	434	522	711	780
NOx (HFO) (ppm)	309	442	533	725	791

Diagram 1 Simulator comparison of NOx emissions on three types of fuel and different loads

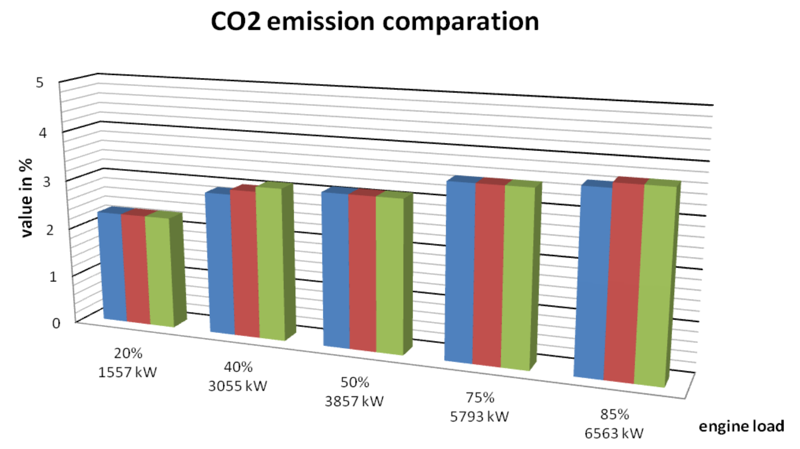
Source: Author

4.2. CO_2 emissions on different fuels considering engine load

The diagram 2 shows CO_2 emissions (expressed as a percentage of %) at various engine loads and at the consumption of three different types of fuel (HFO, MDO and LNG), recorded on the simulator.

It can be seen from Figure 2 that the CO_2 content is constantly increasing in parallel with the engine load at consumption for all three fuel types. It can also be concluded that the share of CO_2 is similar for all three types of fuels, there is no significant difference between gas and liquid fuels.

Since the amount of CO2 emitted is directly proportional to the amount of fuel consumed and energy efficiency, a reduction in its emission can be achieved by reducing SFOC and can be seen from diagram 3.



Engine load	20% 1557 kW	40% 3055 kW	50% 3857 kW	75% 5793 kW	85% 6563 kW
CO2 (GAS) (%)	2.3	2.9	3.1	3.5	3.6
CO2 (MDO) (%)	2.3	3	3.1	3.5	3.7
CO2 (HFO) (%)	2.3	3.1	3.1	3.5	3.7

Diagram 2 Simulator comparisons of CO_2 emissions on three types of fuel and different loads

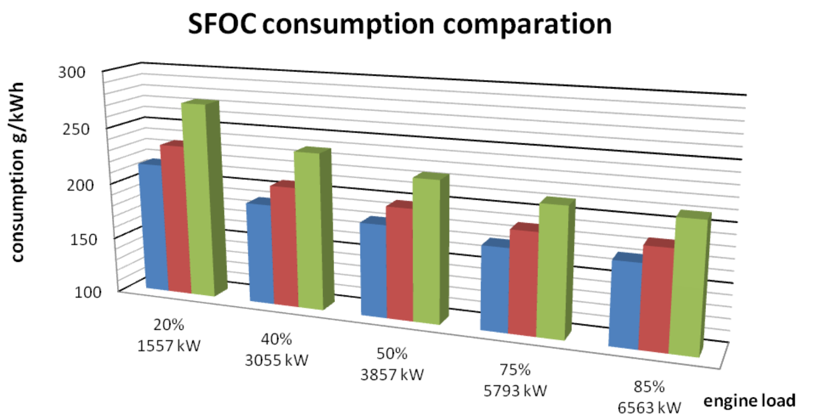
Source: Author

4.3. SFOC on different types of fuels considering engine load

Diagram 3 shows SFOC, expressed in g/kWh at different engine loads and for three different types of fuel (HFO, MDO and LNG).

It can be seen that LNG has the lowest SFOC followed by MDO and that the highest specific fuel consumption is when the engine uses HFO.

The diagram shows that SFOC is higher for all three types of fuel at lower engine load and gradually decreases in parallel with increasing engine load.



Engine load	20% 1557 kW	40% 3055 kW	50% 3857 kW	75% 5793 kW	85% 6563 kW
SFOC (GAS) (g/kWh)	216.2	189.3	181.8	172.9	171.8
SFOC (MDO) (g/kWh)	234.8	206.7	198	188.6	186.1
SFOC (HFO) (g/kWh)	273.3	238.3	224.2	212.3	210.8

Diagram 3 Simulator SFOC comparison on three types of fuel and different loads

Source: Author

5. MEASUREMENT RESULTS FROM THE TEST BED

In this chapter, measurements for NOx, CO_2 and SFOC from the engine test-bed are presented and comparisons are made in relation to the type of fuel and the engine load.

Test-bed – LNG Ship general characteristics:

- Length: 290 meters.
- Breadth: 45.6 meters.
- Design draft: 11.7 meters.
- Speed service approx.: 19.5 knots.
- Cargo Tank capacity: 174,100 m3.

Test-bed - Ship Engines general characteristics:

- Manufacturer: MAN B&W
- Type: 8L51/60DF
- Type: Four-stroke, in-line, dual fuel, turbocharged
- Rated power: 8,000kW (MCR) on LNG, 8,000kW(MCR) on MDO
- Speed: 514 rpm
- Cylinder bore: 510mm
- Piston stroke: 600mm
- No. of cylinders: 8

There are five main dieselgenerator engines fitted on board the vessel. Engines are in-line 8 cylinder MAN8L51/60DF, capable of producing 8,000kW. All of the engines have been designed to run on either boil-off gas from the cargo tanks or marine diesel oil (MDO) from the fuel oil service tanks.

Even though the two fuels have a slightly different calorific value, the engines can run equally well on either gas or MDO/HFO and can deliver the same maximum power output on either fuel. The engines can also be switched from one fuel to the other while still operating on load and without any interruption to the power supply. The MAN 8L51 / 60DF engines are used to drive direct coupled alternators that supply electricity to all of the ship's systems including the main propulsion plant which uses electric motors to drive conventional propellers through a reduction gearbox.

In gas mode, the engines run as lean burn engines according to the Otto cycle. Ignition is initiated by injecting a small amount of diesel oil in the form of pilot fuel which provides a high energy ignition source for the main fuel gas charge in the cylinder. The 'micro-pilot' injection system uses less than 1% of nominal fuel amount.

In liquid fuel mode, the engines work just like a conventional diesel engine, utilizing a traditional 'jerk' type fuel injection system. Transfers between the two operating modes take place without interruption in the power supply. Control of the fuel system in this way ensures that the combustion stays within the correct operating boundaries and that optimum performance from all of the cylinders is achieved as the quality of the gas and the ambient temperature vary. [6]

The main propulsion system consists of two frequency converters supplying a varying frequency supply from the main electrical network to two synchronous electric motors. The two motors provide dual inputs to a reduction gearbox which has a single shaft output driving a fixed pitch propeller. The motors are rated at 13.5MW each and are coupled to the main reduction gearbox which drives the propeller shaft. Each motor is a double wound with two three-phase windings. The frequency converters allow 'four quadrant operation' which means the motor can be driven and braked in each direction.

Each propulsion system consists of the following main components:

- Two 8,100kVA star / star-delta transformers connected to one of the 6.6kV main switchboards
- The propulsion converter with independent control system
- The dual wound synchronous motor capable of zero to 720 rpm in each direction.

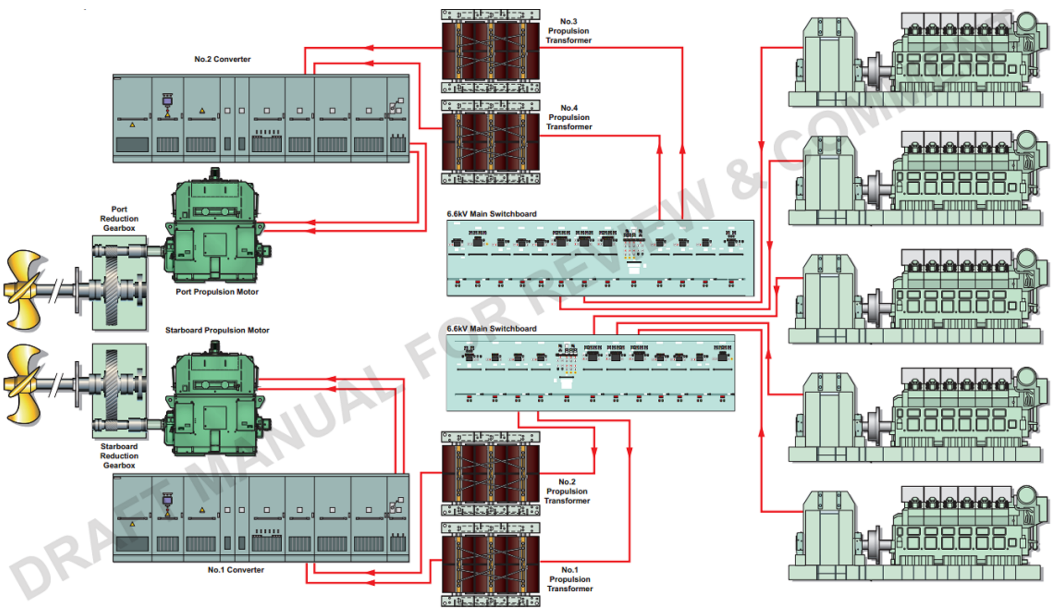


Figure 1 Simplified Connection Arrangement of Diesel Generators, Main Switchboards and Propulsion Equipment [6]

Measurements on the test bed were performed on two different types of ship propulsion fuel:

- MDO - Marine diesel oil and
- LNG - Liquefied natural gases

Comparisons of NOx and CO2 emissions at the following loads are shown graphically:

- 25% load (4000 kW)
- 50% load (4000 kW)
- 75% load (6000 kW)
- 100% load (8000 kW)

SFOC at the following engine loads is shown:

25% load (4000 kW)
50% load (4000 kW)
75% load (6000 kW)
85% load (6800 kW)
100% load (8000 kW)

5.1. NOx emissions (test-bed) on different fuel types considering engine load

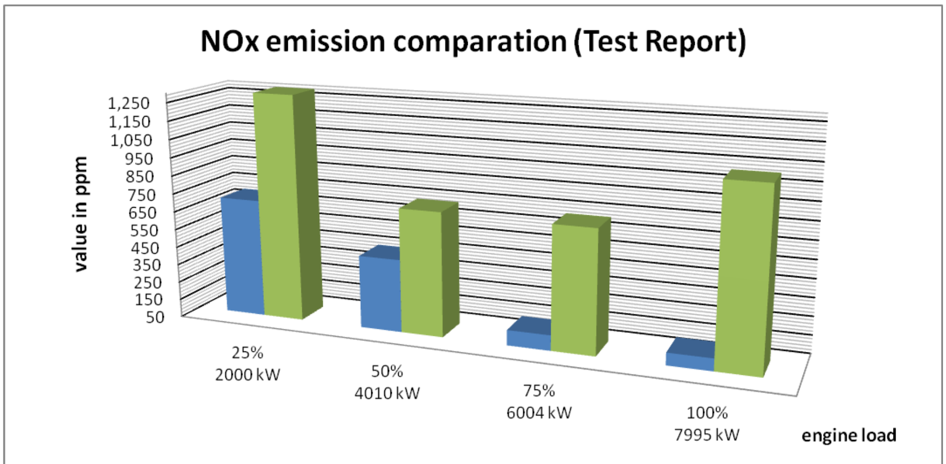
Diagram 4 shows NOx emissions (ppm) measured on a test-bed, at various engine loads and when consuming two types of fuel (MDO and LNG).

Unlike the measurements on the simulator (diagram 1) where the NOx emission is lower at lower engine loads and increases according to the engine load for all three types of fuel (HFO, MDO and LNG), it can be noticed that when measuring on a test-bed a completely different trend is occurred and that NOx emissions are higher at lower engine loads and that they decrease in line with higher engine loads for both fuels (MDO and LNG).

With engines consuming LNG as a propellant, a constant decrease in NOx emissions is observed in relation to the increase in engine load to diesel, a constant decrease in NOx emissions is evident up to 75% engine load and then NOx emissions increase at 100% engine load.

As with the measurements on the simulator, a large difference in NOX emissions is noticeable regarding the type of fuel that the engine consumes. On LNG, NOx emissions are significantly lower compared to when the engine is running on MDO.

This trend of NOX emissions from the test-bed can be explained by the fact that formation of NOx in a diesel engine depends on the combination of high temperatures, the availability of oxygen and nitrogen, and the duration of combustion. Because the formation of NOx is highly dependent on the combustion temperature, the formation rate on the exhaust gases increases at higher temperatures.[1]



Engine load	25% 2000 kW	50% 4010 kW	75% 6004 kW	100% 7995 kW
NOx (GAS) (ppm)	704.6	452.1	134.4	118
NOx (MDO) (ppm)	1299.6	733.9	724.5	1017.7

Diagram 4 Test-bed comparisons of NOx emissions on two types of fuel and different loads

Source: Author

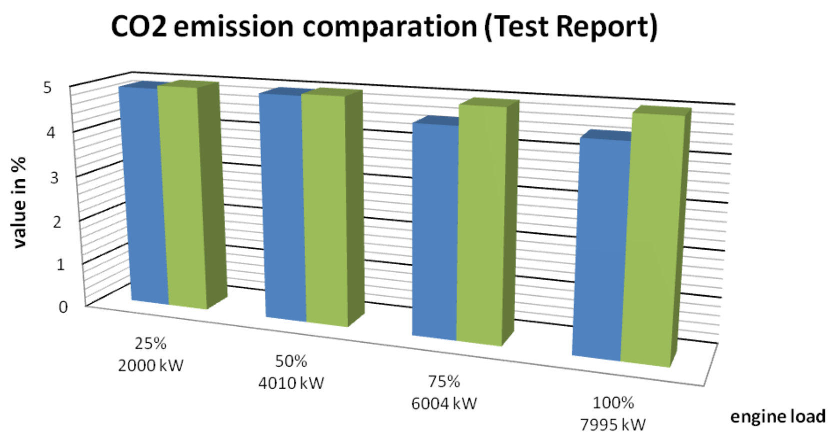
5.2. CO_2 emissions (test-bed) on different fuel types considering engine load

Diagram 5 shows the CO_2 emissions (%) from the test-bed, at various engine loads and at the consumption of two types of fuel (MDO and LNG).

It can be seen from the diagram that the CO_2 content of both fuels is similar regardless of engine load.

When measuring on the simulator (diagram 2) the CO_2 content constantly increases in parallel with the engine load, while when measuring from the test-bed only a slight decrease in CO_2 content compared to the initial engine load (25%) and maximum load (100%) is noticed:

- MDO from 5.59% to 5.51% CO_2,
- LNG from 4.93 to 4.46% CO_2.



Engine load	25% 2000 kW	50% 4010 kW	75% 6004 kW	100% 7995 kW
CO2 (GAS) (%)	4.93	4.96	4.54	4.46
CO2 (MDO) (%)	5.59	5.12	4.97	5.51

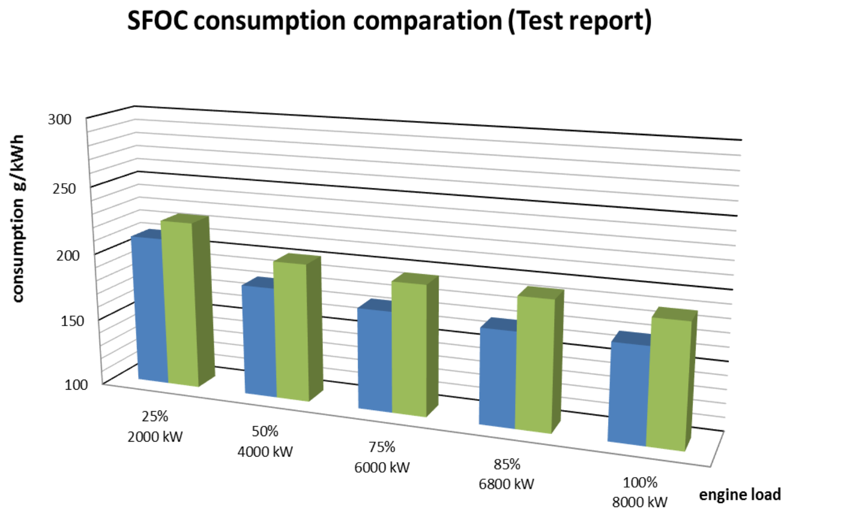
Diagram 5 Test-bed comparisons of CO2 emissions on two types of fuel and different loads

Source: Author

5.3. SFOC on different types of fuels considering engine load

The diagram 6 shows SFOC, expressed in g/kWh at different engine loads and for two different fuel types (MDO and LNG).

As with the measurements on the simulator, it is noticed that the SFOC is higher for both fuel types at lower engine load and gradually decreases in parallel with the increase in engine load.



Engine load	25% 2000 kW	50% 4000 kW	75% 6000 kW	85% 6800 kW	100% 8000 kW
SFOC (GAS) (g/kWh)	210.8	182.1	174.2	169.7	169.7
SFOC (MDO) (g/kWh)	224.6	202.1	196	194.6	189.1

Diagram 6 Test-bed SFOC – two types of fuel comparison on different loads

Source: Author

It is also evident, when the engine is running on LNG, that the specific fuel consumption is significantly lower than the MDO at all engine loads, which is explained by the difference in the calorific value of these two fuels. The LNG lower calorific value is 48 MJ / kg, which is more than for MDO, for which the lower calorific value is 42.7 MJ / kg. [8]

Table 3 Volumetric density and low calorific value (LCV) for different oils [8]

Fuel Type	Kg/m^3	MJ/kg
LNG	450	48
HFO	991	40.2
MDO	900	42.7

6. RESULTS COMPARISON MEASURED ON THE SIMULATOR AND TEST BED

In this chapter, data comparison from the test-bed and a ship simulator of the same engine type with the same fuel and the same load is graphically made and analyzed. Data for NOx, CO_2 and SFOC are presented and analyzed.

NOx and CO_2 emissions are graphically shown by comparisons on the same fuel type and on two different engine loads:

- 50% load (4000 kW)
- 75% load (6000 kW).

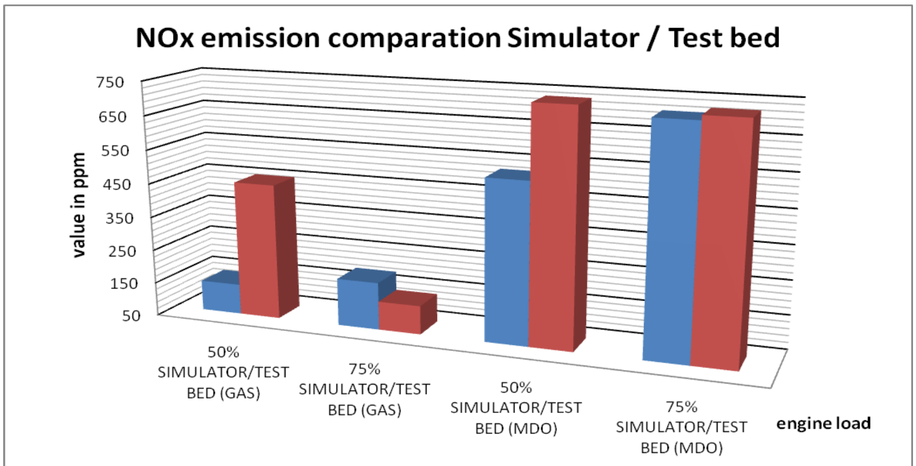
Specific fuel consumption (SFOC) is also shown and compared at three different loads in which the engine most often runs in real conditions:

- 50% load (4000 kW)
- 75% load (6000 kW)
- 85% load (6800 kW).

Diagram 7 compares the results of NOx emission measurements (expressed in ppm) from the test-bed and the ship simulator, on the same type of fuel and at two engine load points.

At lower engine load (50% load) and when consuming LNG fuel, it can be seen that NOx emissions from the test-bed are significantly higher (323% higher) compared to the measurements taken from the simulator, while at higher engine load (75% load) and at consumption of the same type of fuel (LNG) this ratio is completely changed and the NOx emission is higher by approximately 56% but for measurements taken on a ship simulator.

At lower engine load (50% load) and when consuming MDO fuel, it is visible that the NOX emission from the test-bed is approximately 29% higher compared to the measurements taken from the simulator, while at higher engine load (75% load) and when consuming the same type fuel (MDO) this ratio is much more even, i.e. NOx emissions from the test-bed are slightly less than 2% compared to the measurements taken from the simulator.



Engine load	50% SIMULATOR/TEST BED (GAS)	75% SIMULATOR/TEST BED (GAS)	50% SIMULATOR/TEST BED (MDO)	75% SIMULATOR/TEST BED (MDO)
NOx (SIMULATOR) (ppm)	140	190	522	711
NOx (TEST BED) (ppm)	452.1	134.4	733.9	724.5

Diagram 7 Simulator/Test-bed comparisons of NOx emissions on two types of fuel and different loads

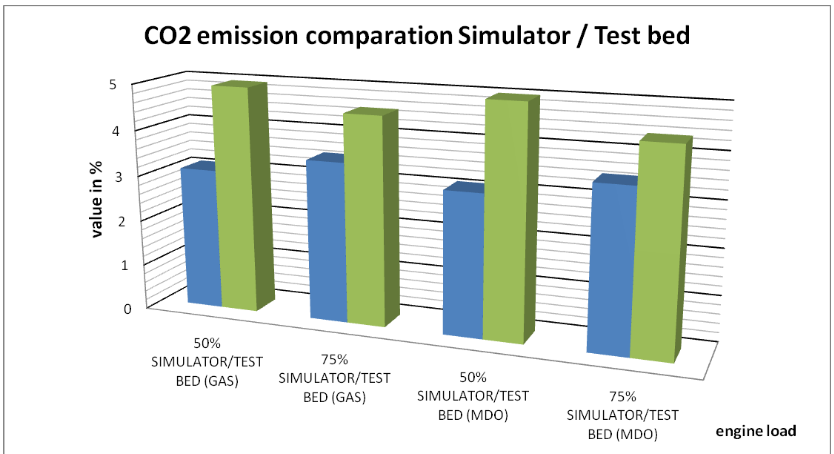
Source: Author

Diagram 8 compares the measuring results with the share of CO_2 emissions (%) from the test-bed and the ship simulator, on the same type of fuel and at two engine load points.

The above-mentioned shows that according to the measurement results via simulator, the share of CO_2 emissions is slightly lower compared to the emissions from the test-bed.

On lower engine simulator at lower load (50% load) the share of CO_2 emissions is the same (3.1%) regardless of the type of fuel (LNG and MDO). At higher engine load (75% load) the share of CO_2 increased slightly (3.5%) and is also the same for both types of fuel (MDO and LNG).

According to the results taken from the test-bed, it is noticeable at lower engine load (50% load) and when consuming different types of fuel (MDO and LNG) the share of CO_2 emissions is slightly higher compared to measurements at higher engine load (75% load) while consuming the same fuel types (MDO and LNG).



Engine load	50% SIMULATOR/TEST BED (GAS)	75% SIMULATOR/TEST BED (GAS)	50% SIMULATOR/TEST BED (MDO)	75% SIMULATOR/TEST BED (MDO)
CO2 (SIMULATOR) (%)	3.1	3.5	3.1	3.5
CO2 (TEST BED) (%)	4.96	4.54	5.12	4.37

Diagram 8 Simulator/Test-bed comparisons of NOx emissions on two types of fuel and different loads

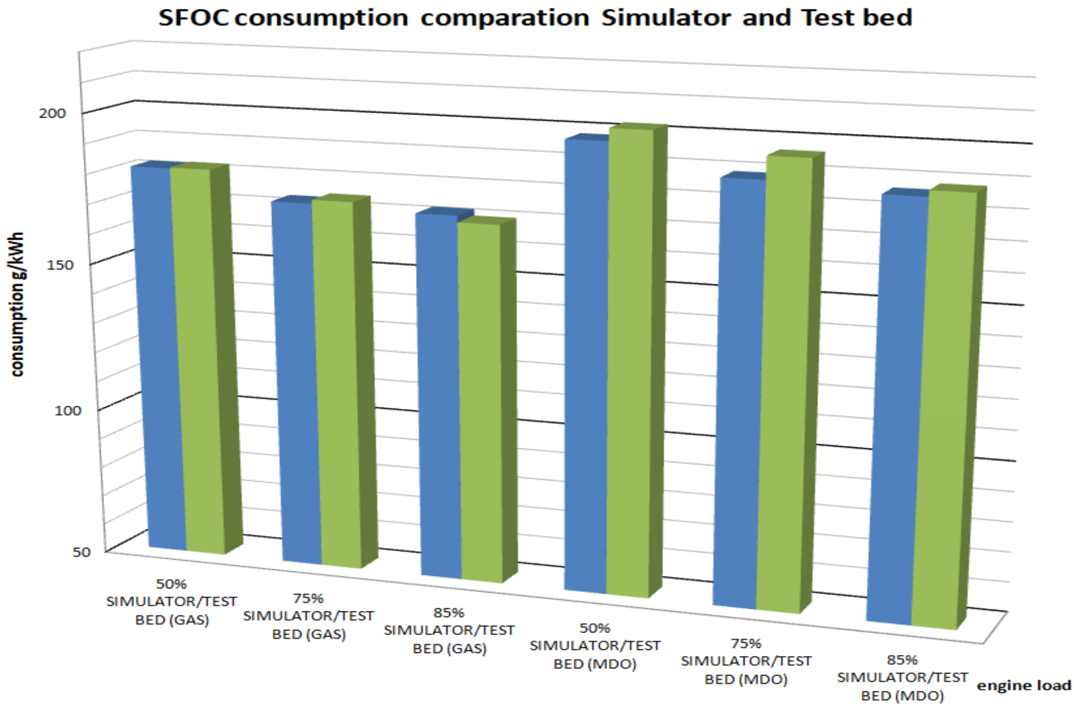
Source: Author

Diagram 9 compares the results of SFOC measurements from the test-bed and the ship simulator. Comparisons were made on two fuel types (LNG and MDO) and on three engine load points.

When operating the engine on both types of fuel (LNG and MDO), the diagram shows that the SFOC is higher at lower engine load and that it decreases in parallel with the increase in engine load.

Also, due to the difference in calorific value (see Table 3), it is noticed that SFOC is slightly lower when using LNG fuel compared to MDO.

According the conclusion - the specific fuel oil consumption is identical according to the results obtained on the ship simulator and according to the results taken from the test-bed at three different loads and on two types of fuel.



Engine load	50% SIMULATOR/TEST BED (GAS)	75% SIMULATOR/TEST BED (GAS)	85% SIMULATOR/TEST BED (GAS)	50% SIMULATOR/TEST BED (MDO)	75% SIMULATOR/TEST BED (MDO)	85% SIMULATOR/TEST BED (MDO)
SFOC SIMULATOR (g/kWh)	181.8	172.9	171.8	198	188.6	186.1
SFOC TEST BED (g/kWh)	182.1	174.2	169.7	202.1	196	188.1

Diagram 9 Simulator/Test-bed SFOC comparisons on two types of fuel and three different loads

Source: Author

7. CONCLUSION

Although liquefied natural gas (LNG) contains less carbon per unit of energy than conventional marine fuels MDO and HFO, its use according to the results obtained in this work in both cases simulator and test-bed did not significantly reduce fraction of CO_2 in exhaust gas.

According to the results on the test bed and on the simulator NOx emissions are multiple lower when the engine is running on LNG compared to MDO and HFO. Also, it can be concluded that NOx emissions are slightly higher when the engine is running on HFO compared to MDO in both simulator and test-bed cases.

As seen from the obtained results (chapter 6.) when consuming LNG fuel, the oscillations of the obtained NOx emissions from the test-bed and simulator are large. At lower engine load (50% load) by as much as 323% while at higher engine load (75% load) this difference is 56%. Based on this results it can be concluded that the reliability of the simulator compared to the measurements taken on the test-bed when running the engine on LNG fuel is quite low.

When the engine is running on MDO, at lower engine load (50% load) NOx emissions from the test-bed is approximately 29% higher compared to the measurements taken from the simulator, while at higher engine load (75% load) this ratio is much more equal, i.e. NOx emissions from the test-bed are slightly less than 2% higher than the measurements taken from the simulator. From the results of measuring NOx emissions when the engine is running on MDO, it can be concluded that the reliability of the results of emissions taken from the simulator is much more realistic compared to when the engine consumes LNG.

According to results in recording CO_2 emissions, taken from the simulator, it is noticeable that at higher (75% load) and lower engine load (50%) and when consuming both types of fuel (LNG and MDO) the share of CO_2 emissions is much lower compared to the results with test-bed. This difference is noticeable and averages approximately 45% for all measurements. From this it can be concluded that the reliability of the simulator for measuring CO_2 emissions is also not so high.

The simulator quite realistically showed SFOC with various loads and two types of fuel. The consumption obtained on the simulator and the consumption from the test-bed are similar and therefore it can be defined that, in this very sense, the reliability of the simulator is quite high.

In addition to commercial aspects, the main argument for believing in LNG as a marine fuel and in replacing conventional fuels (HFO and MDO) according to the results in this paper with LNG is a significant reduction in air pollution, primarily from NOx emissions and also a slight reduction in the greenhouse gas of CO_2 taking into account the lower SFOC.

REFERENCES

[1] Karin Andersson, Selma Brynolf, J.Fredrik Lindgren, Magda Wilewska-Bien: Shipping and the Environment-Improving Environmental Performance in Marine Transportation, ISBN 978-3-662-49043-3 ISBN 978-3-66249045-7 (eBook) DOI 10.1007/978-3-662-49045-7

[2] Ivan Komar and Branko Lalić: Current Air Quality Issues, Chapter 8 Sea Transport Air Pollution, 2015, available on https://cdn.intechopen.com/pdfs/48071.pdf (accessed10 February 2021)

[3] Nitrogen Oxides (NOx) – Regulation 13 available on https://www.imo.org/en/OurWork/Environment/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx (accessed12 January 2021)

[4] NOx Technical Code 2008 Technical code on control of emission of Nitrogen oxides from marine diesel engines - MEPC/Res. 177(58) available on https://puc.overheid.nl/nsi/doc/PUC_2411_14/2/ (accessed 25 February 2021)

[5] IMO and the UNFCCC policy framework -https://www.imo.org/en/OurWork/Environment/Pages/Historic%20Background%20GHG.aspx (accessed 04 March 2021)

[6] CESI QINGDAO Machinery Operating Manual

[7] Analysis of exhaust gas emission in the marine two-stroke slow-speed diesel engine B Lalić, G Radica, N Račić Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike 67 (3), 17-35, available on https:// www. researchgate.net/publication/305877124 (acessed 27. February 2021)

[8] Experimental investigation of exhaust emission from marine diesel engines L Mihanović, M Jelić, T Sumić, G Radica, N Račić 2020 5th International Conference on Smart and Sustainable Technologies (Split Tech) available on https://ieeexplore.ieee.org/document/9243740, (acessed 24.February 2021)

[9] Tan, R., Duru, O., & Thepsithar, P. (2020). Assessment of relative fuel cost for dual fuel marine engines along major Asian container shipping routes. Transportation Research Part E: Logistics and Transportation Review, 140, 102004. doi:10.1016/j.tre.2020.102004 – available on https://www.sciencedirect. com/science/ article/abs/ pii/S1366554520306554 (acessed on 08.03.2021)

[10] https://www.imo.org/en/OurWork/Environment/Pages/GHG-Emissions.aspx (acessed on 18.03.2021)

MONTENEGRIN MARINAS BEFORE AND DURING THE COVID-19 PANDEMIC: COST LEADERSHIP STRATEGIC PERSPECTIVE

Dragana Milošević
University of Montenegro, Faculty of Maritime Studies Kotor
Kotor, Montenegro
E-mail: dmilosevic27@gmail.com

Ivona Milić-Beran
University of Dubrovnik, Maritime Department
Dubrovnik, Croatia
E-mail: ivona.milic-beran@unidu.hr

Senka Šekularac-Ivošević
University of Montenegro, Faculty of Maritime Studies Kotor
Kotor, Montenegro
E-mail: senkas@ucg.ac.me

UDK 656.615:338.48(497.16)
616-036.21"2019"

Summary

Modernization and expansion of a range of services create inevitable competitiveness between modern marinas. Montenegro has positioned itself as an attractive nautical destination since 2006 due to a significant number of foreign investments in maritime tourism. Thus, a traditional Montenegrin nautical offer has been complemented by the newly built marina complexes Porto Montenegro, Luštica Bay, D-Marin Portonovi, and Lazure. Today, Montenegro has eleven marinas with about four thousand berths. Official statistical data for the last ten years shows a permanent growth in the number of yachts and passengers entering the territorial waters of Montenegro. The situation changed drastically during the COVID-19 pandemic in 2020 when the traffic of vessels and passengers significantly decreased in comparison to the previous period of time. According to Porter's typology, the concept of business strategies distinguishes three generic competitiveness strategies that are also appropriate for marinas' business. Thus, this paper aims to determine how the businesses of Montenegrin marinas changed during the pandemic period from the cost leadership strategic perspective. The changes in the cost leadership strategy in marinas before and during the pandemic were determined by the Wilcoxon Matched-Pairs Signed Ranks Test. The authors explored twelve variables of this strategy. The sample includes a survey of the attitudes of marina managers in the operations, marketing, finance, and other business sectors of Montenegrin marinas. The results show that the cost leadership strategy before the pandemic (i.e., before 2020) is dominant in 12.5% of marinas in Montenegro, while today, it is predominant in 43.75% of them. Significant changes in the strategy include strict cost control, procurement of means of the work, marketing costs, prices and price discounts, and marinas' services delivery. These results prove that in the turbulent times of the COVID-19, marinas are changing the competitive strategies from differentiation of the nautical offer to the cost leadership strategy, which defines the paper's originality.

Keywords: marina, Porter's cost – leadership strategy, COVID-19, competitiveness, maritime tourism

1. INTRODUCTION

Maritime tourism in recent decades has become a significant trend in the global tourism industry, primarily because of socio-economic and demographic changes and the growing interest in amateur maritime, yachting, and cruising [3; 6].

The lack of scientific research on nautical tourism is underlined by recent studies [18]. In the marina business, on the other hand, even before the COVID-19 pandemic, the following trends emerged [43; 22]:

- eco-responsibility of marinas and the concept of green marinas,
- the growth of the clientele, precisely due to the new generation of millennials as new clients' profile with specific needs and desires,
- more efficient marina management technology and software (digital reservation, automated billing, more accessible communication, connection with social media, and online performance indicators in real-time), and
- improvement of the infrastructure of marinas, taking into account more frequent extreme weather events and the use of suitable materials for the environment.

However, under the influence of the global pandemic, significant changes have taken place in the maritime tourism industry in general, and particularly in marinas. This industry has been affected by the pandemic crisis in all three business segments: cruising, yachting, and marinas business [3; 4; 18; 19; 25].

The negative consequences of pandemics significantly affected the cruise industry. It has largely suspended operations worldwide, as health measures suppressing the pandemic do not recommend using mass accommodation facilities offered by cruise ships [39]. In addition to travel bans and significant financial losses, blue cruise companies responded to the pandemic by developing new marketing strategies with the concept of not transmitting corona at sea, offering vacations away from land in safe and hygienic conditions in line with epidemiological measures [3]. Cruise lines must be careful in choosing business strategies.

In the yachting sector, the COVID-19 pandemic has implications in general for concerns about the business future, specifically for pricing policies and difficulties in providing funds and attracting customers. The COVID-19 situation has reduced prices and increased general yacht management costs [4]. The -19 crisis has affected recreational navigation in changing routes due to the current restrictions, i.e. closing borders, mandatory quarantine, etc. In addition, the pandemic has influenced navigation decisions in terms of less frequent and relatively shorter voyages [18].

When it comes to marinas, the number of yachts in marinas has decreased. Personal protective equipment (masks, disinfection, gloves) is strictly used in marinas, while delivering of services of catering and shopping is complex. Also, looking for marinas, sailors rather keep their distance [18]. Applying berth rate discounts to ease aggregative revenue loss and stimulate financial recovery is a typical response to a crisis. However, this does not reduce cumulative losses [37].

Despite the negative business results, some marinas have managed to take advantage of this crisis to attract new users who have massively cancelled vacation plans, looking for safer ways to recreate outdoor activities closer to home [17]. During COVID-19 restrictions, marinas have adapted to the situation by applying digital marketing, reviewing or postponing events, performing safe operations according to prescribed health measures, etc [20].

Previous research shows that a pandemic crisis will affect changes in the habits of international tourists, and an interest in more individual types of travel will increase (e.g., holidays on yachts, the use of private airplanes and tours organization, vacations at small villas and bungalows) [40; 4]. This is supported by the fact that 2020 is considered the year of the prosperity of the yachting industry. There have been records in yacht sales and a significant increase in demand for yacht investments. Yacht owners have realized that this is an ideal, safe and intimate type of vacation, which has directly caused a remarkable increase in the price of superyachts [21]. Superyacht brokerage achieves record sales, breaking 46% [38]. To avoid COVID-19 travel restrictions, rich people spent more than £ 1bn on superyachts in 2021 [10]. The individual nature of yachting tourism, in which marinas play a significant role, will make it easier to overcome the crisis than the cruising industry [25].

This paper investigates the implications of the pandemic on the business strategies of Montenegrin marinas. In this sense, the authors conduct a comparative analysis of cost leadership strategy implementation before and during the pandemic, on the example of Montenegrin marinas.

Before the pandemic, there was an increase in the number of marinas in Montenegro. It resulted in the need for marinas managers to create strategies to gain a competitive advantage in the market. Additionally, the competitive rivalry among marinas has been intensified by newly built exclusive marinas that apply high standards in business operations. In a competitive environment, marinas should maintain operability, profitability, develop business while maintaining and improving the quality of services [16]. Therefore, this paper reviews relevant and current literature sources, publications and reports, official marina sites, statistics and explains the competitive marina market in Montenegro. On the other hand, the authors identify variables that influence the cost leadership strategy and their changes during the pandemic based on primary research. The main research question is: *What are the specific changes in the cost leadership strategy in Montenegrin marinas during the pandemic if there is an earlier implementation of this strategy used for comparison?*

The paper begins with the concept of generic competitive strategies (cost leadership, differentiation, and focusing), relying on their general and practical applicability, well-defined structure, clarity, and simplicity [2; 31]. Some experiences of competitiveness in the maritime tourism industry have been gained since the 2008 economic crisis [24]. For example, the cruise industry significantly lowered prices to cover basic operating costs, which later proved to be a successful strategic option [37]. Another example is registered during the ecological crisis when yacht charter agencies were more inclined to choose low-cost strategies than before the crisis. Interestingly, the other two competitive strategies (differentiation and focusing) did not show a significant change caused by the crisis. However, it is essential to point out that differentiation is the dominant strategy applied by agencies of this type [47].

Therefore, in this paper, a generic cost leadership strategy is analyzed to check its applicability in marina operations during the COVID-19 crisis, based on the abovementioned examples. The paper also aims to check whether the cost leadership strategy has replaced the dominant strategy of differentiation in marina operations, as proven in earlier references [5; 41; 26].

1.1. Montenegrin marinas and COVID-19 implications on their business

International investors have recognized Montenegro as an attractive nautical destination since 2006. Modern marine complexes along the Montenegrin coast (Porto Montenegro, Luštica Bay, D-Marin Portonovi, and Lazure) have been built from that period. The total number of marinas in the world reaches 25,000, out of which there are 4,500 to 10,000 marinas in Europe. Uncertainty about the exact number of marinas and their capacity lies in the fact that there is no universal definition and classification of marinas, so it is often difficult to make a clear distinction between moorings and marinas. Also, marinas' activities are coded as "other entertainment and recreational activities," which further complicates the assessment of the size of the marine sector in Europe [9; 11]. Today, Montenegro offers eleven marinas with about four thousand berths (Figure 1).

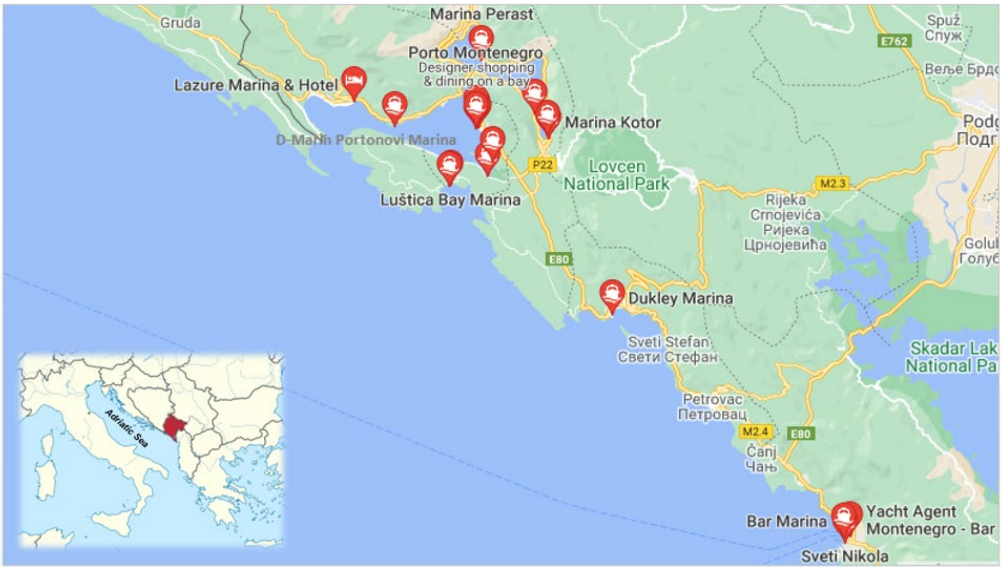


Figure 1 The geographical position of Montenegrin marinas

Source: Authors according to Google maps [12]

Recent progress achieved in the marine business in general, and especially in Montenegro, is noted in the following business segments:

- expansion and modernization of infrastructure capacity with particular emphasis on increasing the length of berths to accommodate mega and superyachts;
- expansion of the service range to restaurants, sports, and entertainment facilities with the improvement of boat mooring services;
- long-term lease of berths or slips in the marina;
- involvement of regulatory agencies in marina operations;
- provision of the compliance with environmental and safety standards, especially in the field of waste management; and
- construction of luxury marina settlements [8].

Official statistics show a permanent increase in the entry of yachts and passengers into the territorial waters of Montenegro (see Table 1) [27]. The leading position in the total turnover of superyachts in the Mediterranean is reserved for Italy (18.9%), followed by France (15.9%) and Spain (12%). Montenegro generates 6.30% of the total turnover of superyachts, which is a significant percentage compared to the existing infrastructure and competition (Monaco 11.1%; Greece 9.3%; Croatia 7.50%; Turkey 4.20%; Giblartar 3.90%; Malta and Albania 3.30%) [44].

Table 1 The traffic of nautical vessels and passengers in Montenegro in the 2010-2020 period

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Yachts	2878	2964	2987	3786	3961	4018	4384	4598	4710	4775	1858
Passengers	12877	13977	14494	15778	18129	20859	21554	23001	27685	28562	7458

Source: [27]

Compared to 2019, an enormous decline in the domain of cruising was recorded in 2020. In total, 98.2% fewer cruises and 99.5% less passenger traffic were achieved in 2020 [27].

During 2020, 1858 vessels for leisure, sports, and recreation entered the territorial sea of Montenegro, which is 61.1% less than in 2019. The number of passengers on these vessels in 2020 was 7458, which represents a decrease of 73.9% compared to 2019 [27].

As far as Croatia is concerned, there was a significant decline in the share of charter services of 31.37% during 2020, although this sector has achieved a dynamic growth in the last five years, with projections of the continuation of this trend [19].

All the above results are expected due to the quarantine period from March to May 2020, when it was wholly prohibited to enter the nautical ports of Montenegro. Marinas in Montenegro productively used this period by looking for innovative solutions, informing clients about the situation in the country, modernizing equipment, and training employees for new working conditions [25].

1.2. Application of generic strategies in marinas' business

The marina business is mainly characterized by competition at the local or regional level but is increasingly moving to the international level. The main fields for competition in the marina business are quality of services, prices, and safety [9].

Above-average business performance lies in a sustainable competitive advantage, and the competitive potential is conditioned by the company's strategic capacity [46; 7]. Competitive strategy is a specific plan for achieving competitive superiority and contains ways to compete for the positions of marinas in the market [23]. In this regard, Porter developed three generic competitive strategies: cost leadership, differentiation, and focus, as effective defense mechanisms on the action of five competing forces in the industry (entry of new competitors, bargaining power of buyers and suppliers, the threat of substitute products/services and rivalry between existing competitors) [33; 34].

The cost leadership strategy researched in this paper represents the aspiration of a marina company to position itself based on the lowest costs while implementing strict cost control, minimizing costs of R&D, marketing, sales, and others [33]. The goal is to generate activities more economically than competitors and to avoid those activities that create unnecessary costs [45].

According to the sources, the strategy of differentiation is mainly used in the marina business. Differentiation focuses on achieving the uniqueness of the marketing offer according to its highly ranked attributes in users' perceptions. Differentiation strategy relies either on the physical aspect of the service (design, multiple functionalities, top quality, distribution, visual effect) or the symbolic aspect, i.e., the emotional relationship of customers to the service (reputation, brand, image, promotion) [33; 32].

The focus strategy is applied to a specific, narrower market segment that the company seeks to serve more efficiently and effectively than competitors and may relate to a specific customer profile, product/service line, or geographic area [33]. Focusing has several strategic directions: focusing on low costs, focusing on differentiation, or combined concerning a narrow market goal [31]. By applying a focus strategy, a company builds a reputation as a market expert in a particular field [15].

A modest number of authors have examined the applications of Porter's competitive strategies in maritime tourism [23; 5; 13; 41; 47; 28]. According to research, marinas in normal conditions predominantly apply a differentiation strategy and less often a cost leadership and focus strategy. Differentiation is considered a suitable strategic option because a marina offers a wide range of service attributes that clients highly perceive and value. Furthermore, the sensitivity of clients to the quality of services in marinas is well known. Additionally, marina customers have a high-paying profile of customers who are willing to pay a premium price [5; 41; 26].

In the example of Turkish marinas, differentiation is most prominently achieved by using modern technologies in providing high-quality services. At the same time, cost leadership strategy is most associated with efficient human resources, and focusing strategy is conducive to servicing certain types of yachts [41].

In times of crisis, companies tend to change their market survival strategies [47]. It is recommended that the company's business strategies should be focused on critical competencies and develop a business strategy to better respond to challenges during the pandemic [1]. Porter's concept of five forces remains relevant, but some authors believe that at this specific point in time, additional forces should be included in this concept: COVID progression, COVID containment, government response, business action, and all focused on public sentiment [42].

Research indicates that Porter’s cost leadership strategy is one of the most appropriate business strategies for overcoming the COVID-19 crisis period for SMEs [29; 30].

Hotel resorts, which have the characteristics of modern marina resorts, in the emerging crisis, apply Porter's generic strategies combined: cost leadership to reduce operating costs, differentiation in achieving uniqueness and comparative advantages with COVID constraints, and focus on meeting specific consumer needs and applying strict health protocols for employees and guests [36]. Also, it is necessary to continue the providing conveniences in rent payments to the marina, to provide long-term bank loans and to convenience existing payments [4].

Priorities in future business strategies will be based on the resilience of a whole industry, rather than economic efficiency; quantifying and planning ecological and environmental threats, not on the description of the problem itself; establishing and managing a solid organizational immune system, rather than on short-term profit maximization; and integrating government policy into business policy [42; 14].

2. METHODOLOGY

The paper investigates the application of cost leadership strategy in the following Montenegrin marinas: Marina Bar, Dukley Marina Budva, Marina Kotor, Luštica Bay Marina, Porto Montenegro Marina, D-Marin Portonovi, Lazure Marina & Hotel, Marina Zelenika, Marina Sv. Nikola Bar, Marina Prčanj, and Marina Navar.

Out of a total of 28 sent questionnaires, 16 or 57% were completed. Respondents who participated in the survey are marina executive directors (18%), operations managers (44%), marketing and communications managers (19%), and others (19%).

The authors used the survey method to collect primary data on respondents' attitudes about the generic cost leadership strategy and the 12 variables described in this particular strategy (Table 1). A survey questionnaire was created in Google Drive form and was sent to the email addresses officially available on the sites of the researched marinas.

Table 2 Cost leadership strategy variables

Symbol	Cost leadership strategy variables
CLSV_1	Implementation of strict cost control
CLSV_2	Preparation of detailed cost reports
CLSV_3	Procurement of the most expensive means of work
CLSV_4	Easy provision of the local workforce
CLSV_5	Using an efficient workforce
CLSV_6	Reduction of marketing costs
CLSV_7	Continuous investment in technology modernization with the aim of reducing future costs
CLSV_8	Providing services with the lowest prices compared to competitors
CLSV_9	Lower prices to attract and retain marina clients

CLSV_10	Frequency of customer requests for price discounts
CLSV_11	Frequency of price discounts offered to clients
CLSV_12	Provision of services in marinas in a simple manner

Source: Authors

Specific variables describing a cost leadership strategy are examined based on the specificity of this strategy well-grounded in theory [33]. In this paper, a 5-point Likert scale is applied: 1 - never, 2 - rarely, 3 - sometimes, 4 - often, 5 - always.

In order to determine whether there was a statistically significant difference in the assessment of the importance of costs and the use of certain cost management methods before and during the pandemic, and because it is a small sample and ordinal scaled data, the Wilcoxon test was used. Before testing whether there was a statistically significant difference in the mean value of the cost leadership strategy before the pandemic relative to the business under pandemic conditions, it was determined that the values were not normally distributed, so in this case the Wilcoxon test was used instead of the paired sample t-test.

After identifying variables that were statistically significantly different before and during the pandemic, the effect size was calculated by determining the r coefficient:

$$r = \frac{|z|}{\sqrt{N}}$$

where N is the number of observations in two time intervals. According to the Cohen criterion, the effect size r is as follows: 0.1 = small, 0.3 = medium, 0.5 = large.

3. RESULTS

When analyzing the cost leadership strategy before and during the pandemic, the arithmetic mean of the results (Table 3) shows that, on average, marina managers value and apply the provision of services in marinas in a simple manner (mean 4.5) and the use of efficient labor (mean 4.44) the most on the five-point Likert scale.

During the pandemic, implementing strict cost control (mean 4.44) has the highest rating and application, while before the pandemic, it was the use of an efficient workforce (mean 4.38).

On the other hand, the least applied before the pandemic is reducing marketing costs and providing services with the lowest prices compared to competitors (both with a mean of 2.625). During the pandemic, the least applied were procurement of the most expensive means of work and providing services with the lowest prices compared to competitors (both with a mean of 2.88).

Table 3 Marina managers attitudes towards cost leadership strategy variables before and during a pandemic

Symbol	Cost leadership strategy variables	Mean 1 (before pandemia)	Std. dev. 1	Mean 2 (during pandemia)	Std. dev.2
CLSV_1	Implementation of strict cost control	4,14	1,204	4,44	0,961
CLSV_2	Preparation of detailed cost reports	4,19	1,109	4,25	0,931
CLSV_3	Procurement of the most expensive means of work	3,44	1,094	2,88	1,31
CLSV_4	Easy provision of the local workforce	3,5	1,094	3,25	1,238
CLSV_5	Using an efficient workforce	4,44	0,727	4,38	0,885
CLSV_6	Reduction of marketing costs	2,63	1,088	3,81	0,834
CLSV_7	Continuous investment in technology modernization with the aim of reducing future costs	3,63	1,204	3,1	1,455
CLSV_8	Providing services with the lowest prices compared to competitors	2,63	1,455	2,88	1,088

CLSV_9	Lower prices to attract and retain marina clients	2,81	1,047	3,44	0,814
CLSV_10	Frequency of customer requests for price discounts	3,38	0,806	4,19	0,665
CLSV_11	Frequency of price discounts offered to clients	2,88	0,885	4,31	1,078
CLSV_12	Provision of services in marinas in a simple manner	4,5	0,816	4,06	0,772

Source: Authors

During the pandemic crisis, the percentage of marinas using a cost leadership strategy increased by more than 30%. Before the pandemic, research showed that a cost leadership strategy was prevalent in 12.5% of marinas in Montenegro, while today, it is 43.75%.

Figure 2 shows the average values of the variables defining the cost leadership strategy before and during the pandemic. It can be noticed that only two variables, the preparation of detailed cost reports and the use of an efficient workforce, show minimal changes over the observed periods.

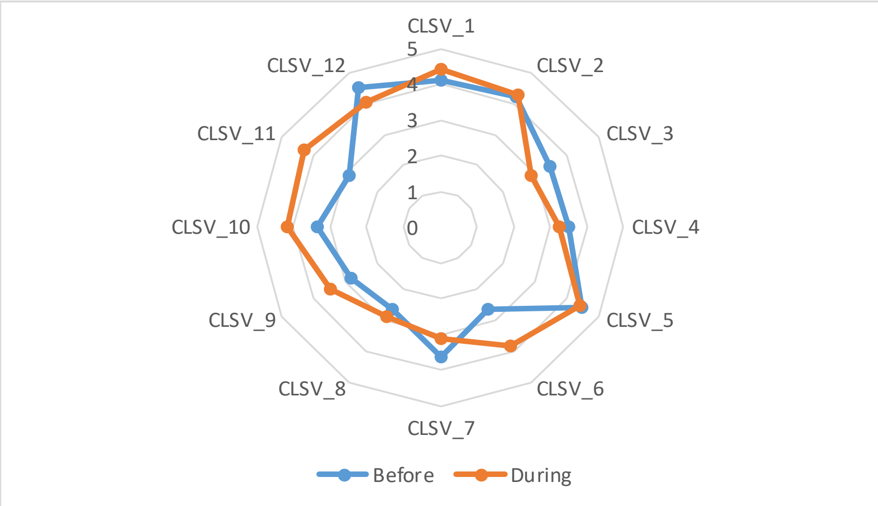


Figure 2 Average values of the cost leadership strategy variables before and during a pandemic

Source: Authors

Furthermore, Figure 2 shows that an increase in average values during the pandemic has happened for most of the variables analyzed. It means that in conducting business policy, most Montenegrin marinas used strict cost control, lower prices, provision of services in marinas in a simple manner, savings in the purchase of expensive means of the work, reduced marketing costs, and related activities. Variables whose average values decreased during the pandemic were: procurement of the most expensive means of work, continuous investment in the modernization of technology to reduce future costs.

Whether the assessment of the importance of a cost leadership strategy changed before and during a pandemic was examined using a Wilcoxon Matched-Pairs Signed Ranks Test. A statistically significant difference was found in the mean scores of the cost leadership strategy from before the pandemic to the time of the deal under pandemic conditions. Under the pandemic conditions, the mean values of the strategy are higher, and the additionally calculated coefficient of the effect size $r = 0.52$ shows a vast influence of the pandemic. The median value on the cost leadership strategy scale increased from $Md = 3.4167$ before the pandemic to $Md = 3.833$ during the pandemic. Thus, the COVID-19 pandemic intensified the implementation of a cost leadership strategy, or marinas are just trying to make their business more resilient through efficient cost management.

The Wilcoxon test also examined which of the variables researched were significantly different in the period before and during the pandemic and the effect size of the actual pandemic on the significantly different variables.

It was found that there was a statistically significant difference in the implementation of strict cost control (CLSV_1), procurement of the most expensive means of the work (CLSV_3), reduction of marketing costs (CLSV_6), lower prices to attract and retain marina clients (CLSV_9), frequency of customer requests for price discounts (CLSV_10) and provision of services in marinas in a simple manner (CLSV_12) as shown in Table 4.

Table 4 Wilcoxon test results and effect size of the pandemic COVID-19

Symbol	Variable	z-value	p	R
CLSV_1	Implementation of strict cost control	-2,236	0,025	0,395
CLSV_2	Preparation of detailed cost reports	-1,000	0,317	
CLSV_3	Procurement of the most expensive means of work	-2,251	0,024	0,398
CLSV_4	Easy provision of the local workforce	-0,811	0,417	
CLSV_5	Using an efficient workforce	-0,577	0,564	
CLSV_6	Reduction of marketing costs	-2,961	0,003	0,53
CLSV_7	Continuous investment in technology modernization with the aim of reducing future costs	-1,392	0,164	
CLSV_8	Providing services with the lowest prices compared to competitors	-1,190	0,234	
CLSV_9	Lower prices to attract and retain marina clients	-2,428	0,015	0,43
CLSV_10	Frequency of customer requests for price discounts	-3,127	0,002	0,55
CLSV_11	Frequency of price discounts offered to clients	-1,933	0,053	
CLSV_12	Provision of services in marinas in a simple manner	-2,333	0,020	0,41

Source: Authors

In conducting business policy in most marinas of Montenegro during the pandemic, there was an increase in the implementation of strict costs controls and service delivery in a simple manner, lower prices, savings in procurement of expensive means of work, reduced marketing costs and activities. This paper shows that it becomes imperative to conduct strict control of marina costs during a pandemic. The strict control of marina costs is common when there is an environment of business uncertainty and a real possibility to manage only company costs, i.e., when revenue generation is not secure, and the duration of the pandemic is beyond the control of marina management.

During the pandemic, procurement of the most expensive means of work and services with the lowest prices to competitors is almost eliminated to generate income based on concluded contracts directly. A possible direction that would lead to the improvement of business in crisis conditions is to increase the workforce's efficiency.

The medium impact of the pandemic is noticeable in the following variables:

- more significant implementation of strict cost control,
- reduced procurement of the most expensive means of work,
- reduced ability to provide services in a simple manner (complex procedures to prevent the spread of COVID-19), and
- more intensive use of lower prices in attracting and retaining marina customers.

The significant impact of the pandemic is reflected in the reduction of marketing costs and the increasing frequency for price discounts. Thus, the concept of relationship marketing is widely used in times of crisis because it is based on loyalty and strengthening long-term relationships with customers.

For marinas in the pandemic period, it is helpful for management to focus on current operations, overcome the situation by reacting promptly, and seek cost reductions that immediately give results. Also, the provision of services in marinas in a simple manner is related to the previously set goal of the cost leadership strategy to provide services more economically than competitors by reshaping the entire value chain to eliminate those activities that create unnecessary costs [45].

In a time of the pandemic, by digitizing certain services (e.g., bookkeeping and billing, payments, berth reservations), marinas can increase efficiency and thus reduce costs [35]. Also, a low-cost strategic position of a company is achieved by focusing on relatively standardized services [33]. In the conditions of the COVID-19 pandemic, additional entertainment, sports, and recreational services in marinas were under restrictions, which is in favor of the simpler and more standardized provision of services.

4. CONCLUSIONS

The article assumes that the pandemic has many negative consequences on maritime tourism, especially on marinas. As there was an intense competition between marinas in Montenegro in the period before the pandemic, it was considered necessary to investigate what happens to generic competitive strategies, especially to the strategy of cost leadership.

It has been shown that due to the uncertainty of the crisis, marina management has set priorities in managing costs. Thus, the cost leadership strategy shows an increase in importance in almost all of its variables, especially in the areas of implementation of strict cost control, procurement of the most expensive means of work, marketing costs, lower prices to attract and retain marina clients, frequency of customer requests for discounts, and provision of services in marinas in a simple manner. Thus, the research question posed in the introduction to this paper was answered positively, i.e., it was proved that COVID-19 pandemic has a significant impact on the cost leadership strategy in marinas in Montenegro.

The direction of future research is a comparative analysis of the strategies of cost leadership, differentiation, and focus concerning the impact of the COVID-19 pandemic, in order to find the optimal strategic model for overcoming the crisis period, both in the current and in some new challenges, e.g., economic and other future crisis periods of marina operations.

REFERENCES

[1] Abubakar, A. (2020) *Coronavirus (COVID-19): Effect and Survival Strategy for Businesses*. Journal of Economics and Business. Vol.3. No.2. pp. 661-671.

[2] Akan, O., Allen, R. S., Helms, M. M. and Spralls, S. A. (2006) *Critical tactics for implementing Porter's generic strategies*. Journal of Business Strategy. 27 (1). pp. 43–53.

[3] Arli, E. (2020) *Effects of Covid-19 Process in Marine Business: An Evaluation on Marine Tourism Enterprises*. The Eurasia Proceedings of Educational & Social Sciences (EPESS). Vol. 18. pp. 119-123.

[4] Arlı, E. and Bayırhan, I. (2021) *The impact of the COVID-19 pandemic process on yacht operators: Application on a marina in Antalya.* Journal of multidisciplinary academic tourism. 6 (2). pp. 81-88.

[5] Atlay Işık, D. (2010) Yat Turizminde Holistik Pazarlama ve Türkiye İçin Farklılaştırma Stratejileri. Doctoral thesis. Dokuz Eylül Üniversitesi. Sosyal Bilimler Enstitüsü. Izmir.

[6] Bosiron, N. M. (1997) *Marine tourism industry – trends and prospects*. National Seminar on the Development of Marine Tourism Industry in South East Asia at Langkawi, 25 - 28 Septembar. pp. 1-14.

[7] Disi, M. M. (2008) A survey of competitive strategies employed by shipping companies in Kenya. Master thesis. Department of Business Administration. School of Business University of Nairobi.

[8] Dragović, B. (2015) MARINE luke za mala plovila i nautički turizam – ODRŽIVI RAZVOJ. SaTCIP Publisher Ltd. Vrnjačka Banja. Srbija.

[9] ECSIP (2015) Study on the competitiveness of the recreational boating sector. Available at: https://ec.europa.eu/growth/tools-databases/vto/content/study-competitiveness-recreational-boating-sector [Accessed 20/10/2020].

[10] Espiner, T. (2021) Superyacht sales surge as wealthy seek Covid escape. Available at: https://www.bbc.com/news/business-57158371 [Accessed: 30/07/2021].

[11] European Commission (2016) Assessment of the Impact of Business Development Improvements around Nautical Tourism – Final. Available at: https://www.europeanboatingindustry.eu/images/Documents/For_publications/Businessdevelopment-around-nautical-tourism.pdf [Accessed: 27/08/2019].

[12] Google Maps (2021) Marinas in Montenegro. Available at: https://www.google.com/maps/search/mrinas+in+montenegro/@42.4535026,18.3793699,11z/data=!3m1!4b1?hl=en [Accessed: 09/08/2021].

[13] Gross, S. and Lueck, M. (2012) Cruise Line Strategies for Keeping Afloat. In book: The Business and Management of Ocean Cruises. Publisher: CABI. Editors: Vogel, M., Papathanassis, A. & Wolber, B. pp. 63-78.

[14] Huy, Q. (2020) Four Strategic Priorities for the Post-COVID-19 World. Available at: https://knowledge.insead.edu/blog/insead-blog/four-strategic-priorities-for-the-post-covid-19-world-14086 [Accessed: 28/07/2021].

[15] Justinian, J. M. (2015) Application of Porter's Generic Competitive Business Strategies and their Effect on Firm Performance in Zanzibar Hotel Industry. Master thesis. Open University of Tanzania.

[16] Koç, E. and Karataş Çetin, Ç. (2017) Process analysis of "marine operations activities" in marinas: a case study. Dokuz Eylül Üniversitesi Denizcilik Fakültesi Dergisi. Special Issue. pp. 1-26.

[17] Lantz, D. (2020) Getting Through COVID-19 – Adaptation and Change for the Marina Market. Available at: https://www.marinadockage.com/getting-through-covid-19-adaptation-and-change-for-the-marina-market/ [Accessed: 30/07/2021].

[18] Łapko, A. (2021) Nautical Tourism of Polish Sailors in the COVID-19 Pandemic. European Research Studies Journal. Vol. XXIV. Issue 2. pp. 396-406.

[19] Łapko, A., Hącia, E. and Lučić, L. (2021) Nautical Tourism in Croatia and the COVID-19 Pandemic. European Research Studies Journal. Vol. XXIV. Issue 2B. pp. 308-319.

[20] Larimer, W. (2020) Marinas Learn to Market During COVID Restrictions. Available at: https://www.marinadockage.com/marinas-market-during-covid/ [Accessed: 28/07/2021].

[21] Laver, R. (2021) Luxury travel: the 2021 Superyacht trends you need to know. Available at: https://hospitality insights.ehl.edu/2021-superyacht-trends [Accessed: 30/07/2021].

[22] Marina Master (2017) Top Trends Driving The Future Of Marina Management Software Sector. Available at: https://www.linkedin.com/pulse/top-trends-driving-future-marina-management-software-sector-master [Accessed: 30/07/2021].

[23] Martin, F. J. (1995) Elements for the competitive analysis of marinas and other yacht harbours. WIT Transactions on The Built Environment. Vol. 8. pp. 65-72.

[24] Martínez Vázquez, R.M., Milán García, J. and De Pablo Valenciano, J. (2021) Analysis and Trends of Global Research on Nautical Maritime and Marine Tourism. Journal of Marine Science and Engineering. 9 (93). pp. 1-9.

[25] Milošević, D. (2020) The impact of COVID 19 on maritime tourism: challenges and recommendations for Montengro. Student International Scientific Conference. 27 May. BNTU. Batumi.

[26] Milošević. D (2021) Primjena poslovnih strategija za postizanje konkurentske prednosti marina u Crnoj Gori. Magistarski rad. Univerzitet Crne Gore: Pomorski fakultet Kotor. Kotor, rad u objavi.

[27] MONSTAT (2021) Nautički turizam – saopštenja. Available at: https://www.monstat.org/cg/page.php?id=633&pageid=590. [Accessed: 17/07/2021].

[28] Muslu, A. (2018) Analysis of Marin Tourism Crafts Companies' Differentiation Strategy and Modern Management Approaching Behaviors by Various Variables. Turkish Studies -Economics, Finance and Politics. 13 (22). pp. 353-371.

[29] Naradda Gamage, S.K., Ekanayake, E., Abeyrathne, G., Prasanna, R., Jayasundara, J. and Rajapakshe, P. A. (2020) Review of Global Challenges and Survival Strategies of Small and Medium Enterprises (SMEs). Economies 8(4), 79. pp. 1-24.

[30] Ningrum Ambarwati, A. and Riyanto, S. (2020) Analysis of The Use of Low-Cost Strategy for SMEs in Indonesia in Covid Pandemic-19. Journal of Social Science. Vol. 1, No. 4. pp. 122-128.

[31] Ormanidhi, O. & Stringa, O. (2008) Porter's Model of Generic Competitive Strategies: An Insightful and Convenient Approach To Firms' Analysis. Business Economics. 43. pp. 55–64.

[32] Pindelski, M. (2016) COMPETITIVE STRATEGIES: Approaches to Business Strategies. Warsaw School of Economics (SGH).

[33] Porter, M. E. (1980) Competitive Strategy: Techniques for Analyzing Industries and Competitors. First Free Press Edition. A Division of Simon & Schuster Inc. New York.

[34] Porter, M. E. (1985) Competitive Advantage: Creating and Sustaining Superior Performance. The Free Press, A Division of A1acmillan, Inc. New York.

[35] Pundzaite, J. (2020) Marina Management Challenges in Times of Corona: A Guide to Preparing Your Marina for the Upcoming Season. Available at: https://harba.co/marina-management-challenges-in-times-of-corona/ [Accessed: 09/08/2021].

[36] Puspita, Ni P. L. A., Astawa, P. and Mudana, G. (2020) Hotel Strategy in Facing the Covid-19 Pandemic (the Westin Resort Nusa Dua Experience). International Journal of Glocal Tourism. Vol. 2. No. 1. pp. 28-39.

[37] Radic, A., Law, R., Lück, M., Kang, H., Ariza-Montes, A., Arjona-Fuentes, J. M. and Han, H. (2020) Apocalypse Now or Overreaction to Coronavirus: The Global Cruise Tourism Industry Crisis. Sustainability. 12(6968). pp. 1-19.

[38] Robinson, N. (2021) Superyacht brokerage sales up record-breaking 46%. Available at: https://www.boat international.com/business/superyacht-special-reports/how-many-super-yachts-were-sold-in-quarter-one-2021 [Accessed: 30/07/2021].

[39] Rocklöv, J., Sjödin, H. and Wilder-Smith, A. (2020) COVID-19 outbreak on the Diamond Princess cruise ship: estimating the epidemic potential and effectiveness of public health countermeasures. Journal of Travel Medicine. Vol. 27. Issue 3. pp. 1–7.

[40] Samarathunga, W. (2020) Post-COVID19 Challenges and Way Forward for Sri Lanka Tourism. SSRN Electronic Journal. pp. 1-12.

[41] Sevinç, F. and Güzel, T. (2016) Competitive Strategies in Marina Enterprises; Implementations in Turkey. Journal of Travel and Hospitality Management. 13 (1). pp. 60-76.

[42] Sharma, D. and Wanduragala, G. (2020) The new 5 forces shaping strategy in a COVID world. Available at: https://www.kanvic.com/grey-matter/the-new-five-forces-of-strategy-in-a-covid-world [Accessed: 28/07/2021].

[43] Structurmarine (2020) New Trends In International Marinas Management – Montreal Boat Show. Available at: https://www.structurmarine.com/tendances-de-gestion-des-marinas-international/?lang=fr [Accessed: 30/07/2021].

[44] The Superyacht Annual Report (2017) Marinas & Migration. Available at: https://shop.thesuperyachtgroup.com [Accessed: 20/10/2020].

[45] Thompson, A. A., Peteraf, M. A., Gamble, J. E. and Strickland III, A. J. (2016) Crafting and executing strategy: the quest for competitive advantage: concepts and cases: Chapter 5 The Five Generic Competitive Strategies. Twentieth edition. McGraw-Hill Education. New York.

[46] Vrdoljak Raguž, I. i Tolušić, M. (2012) Implementacija porterovih generičkih strategija i postizanje konkurentskih prednosti na primjeru automobilske industrije. Ekonomska misao i praksa. br. 1. ss. 381-398.

[47] Yilmaz, E. and Avci, U. (2017) The effect of crisis as an environmental variable on the competitive strategies of yacht charter agents. Dokuz Eylül Üniversitesi Denizcilik Fakültesi Dergisi. 9 (2). pp. 162-185.

LOGISTICS PROCESSES AND PORT OPERATIONS IN RO-RO TERMINALS

Mateja Paulić
University of Rijeka, Faculty of Maritime Studies, student
Rijeka, Croatia
E-mail: teja.paulic@gmail.com

Ines Kolanović
University of Rijeka, Faculty of Maritime Studies, student
Rijeka, Croatia
E-mail: ines.kolanovic@pfri.uniri.hr

Mirjana Borucinsky
University of Rijeka, Faculty of Maritime Studies, student
Rijeka, Croatia
E-mail: mirjana.borucinsky@pfri.uniri.hr

UDK 656.615:629.545.2
627.32

Abstract

Ro-Ro technology is freight technology which originated in the 19th century, and which has undergone major development since the Second World War. As the name indicates, a special ramp is used to "roll on" and "roll off" the cargo from and onto the vessel. A Ro-Ro terminal consists of the following elements: a gate, gamma-ray station, weighbridges as well as waiting areas. Since the cargo is loaded and unloaded "on wheels", logistics services play a major role in Ro-Ro terminal, and complement port operations, distinguishing between the export and import stream. The flow of export and import stream is oppositional. The export starts at the gate of the terminal, while import begins when the vessel is moored. The import and export processes complete a perfect functioning cycle within the port areas. This paper aims at establishing which logistics processes yield maximum efficiency and exploitation of the potential of Ro-Ro terminals. Research results indicate advantages and disadvantages of Ro-Ro technology and how prompt and reliable port services can be ensured.

Keywords: logistics services, port operations, Ro-Ro technology, Ro-Ro terminal

1. INTRODUCTION

The maritime industry plays an important role in the global trade. Ro-Ro shipping can offer an environmentally friendly and cost-efficient option to meet the transport needs of various industries [6]. Consequently, Roll on-Roll off transport is considered to be a crucial element in the world trade, especially in the automotive industry, truck and other bulk cargo trades. In Ro-Ro technology, goods are transferred horizontally, i.e. on wheels, which means that cargo handling equipment is eliminated [15]. Absence of demand for special cargo handling equipment is the main advantage of a Ro-Ro terminal. Ro-Ro transport enables loading of cargoes to ships through ramps instead of hatches and presents a more flexible alternative to containerisation for carrying both containerised and wheeled cargo [14]. The lack of cargo handling equipment allows unloading and loading of cargo, which means that the vessel is self-sufficient, thus shortening ship's time in port and consequently reducing port costs. Nowadays, Ro-Ro technology is employed in ports around the world, however, there is still room for improvement and a need for compliance with modern technologies to ultimately provide more comprehensive services.

Being a part of the intermodal transport chain, efficient Ro-Ro transport requires a perfect system of logistics services in addition to port operations. Hence, port operations (i.e. "the muscles" of the operation) such as berthing, unberthing and stevedoring, cannot be isolated from logistics services (i.e. "the brain" of the operation). Together, they form a continuous process which begins when the cargo arrives at the gate or at the berth or while it is still on the vessel.

To better understand the process that will be explained in the following sections of this paper, the basic parts of the hypothetical terminal will be explained, and its layout presented in Figure 1. The Ro-Ro terminal can be described as the point at which vehicles and other cargo on wheels is loaded and unloaded. As it consolidates road and maritime transport, it presents a nod. A comparison with other terminals reveals that consolidation on a Ro-Ro terminal is fully integrated into high-speed cargo movement, thus making it efficient. Its efficiency can also be ascribed to the fact that no special cargo-handling equipment is required, only a large square parking area.

A Ro-Ro terminal consists of the following elements: a gate, gamma-ray station, weighbridges as well as import and export waiting areas, as shown in Figure 1.

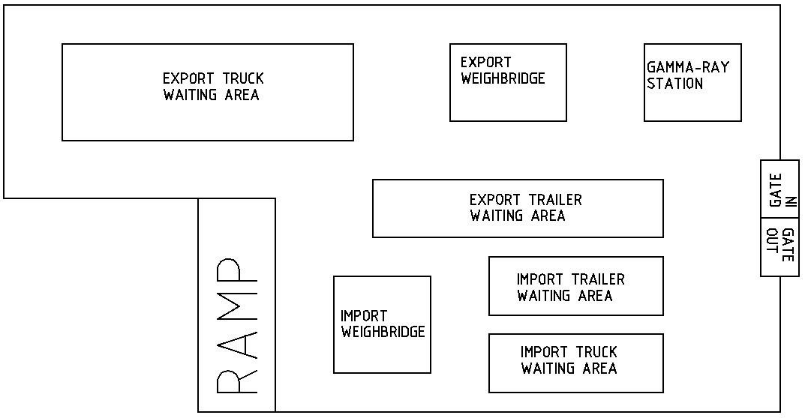


Figure 1 Theoretical layout of a Ro-Ro terminal; Source [10]

Import and export waiting areas are parking lots, which need to be large as cargo cannot be stacked in tiers, as is the case on a container terminal. Thus, to increase storage areas of Ro-Ro terminals, garages are commonly built nearby. Furthermore, as can be seen in Figure 1, a gamma-ray station is required for export only. Import gamma-ray stations are not required as inbound cargo is usually cleared at the import port. In this way, additional storage area can be obtained. It is important to recognize that efficient Ro-Ro port terminals play a fundamental role in providing cargo handling operations which are low cost and time efficient [16].

This paper consists of four parts, which describe services provided on a Ro-Ro terminal and the functioning of the terminal. In addition, logistics processes in Ro-Ro terminals are defined and divided into export and import processes. Further, main port operations, such as berthing and stevedoring, storage, delivery and receipt, are covered in the third part. Finally, a conclusion is presented. The research and results presented in this paper are based on the Bachelor's thesis of the first author [15].

2. LOGISTICS PROCESSES IN RO-RO TERMINALS

Globalization has led to overall market integration, thus making the logistics operations undoubtedly important for continuous market cycle. With the advancement of technology, over the course of time logistics is including more and more activities (also related to increase in product value), all with the purpose of improving the overall service to all customers. Consequently, port logistics, which has an important role in port optimization and increasing its competitiveness on the market, must also move in the same direction. Port logistics processes, especially in Ro-Ro terminals, are complex due to a large number of parties involved and different modes of transport present. The management of parties and modes of transport include managing the flow of materials (in this case cars, trucks and other Ro-Ro cargo) as well as information and ultimately money as a return flow from the customer. All required information generates an enormous mass of data, which lead to efficient management [4].

Services that a Ro-Ro terminal provides can be improved by keeping up to date with technological advances as they impact every aspect of the Ro-Ro terminal operation. Therefore, the Internet of Things (IoT) is implemented in everyday port operations and was identified as one of the best options to achieve improvements in terminal flow regarding the intended purpose of optimizing planning processes [7]. IoT technologies that are indispensable for "intelligent" Ro-Ro terminal functioning are diverse sensors, Radio Frequency Identification (RFID), Wireless Sensor Network (WSN) and Machine to Machine (M2M) [1]. Radio Frequency Identification (RFID) is crucial for the application of IoT technology. Within addition to RFID tags, barcodes, QR Codes and Magnetic ID Cards are used to track vehicles and cargoes on the terminal [1]. Movements are tracked in real time, thus making the exact position of vehicles and cargo known. This will ensure smooth functioning of the terminal and contribute to improved overall performance and services. In this way, bottlenecks may be identified and avoided. Furthermore, pilferage can be suppressed and loss of cargo, especially that of high value, prevented.

Ro-Ro terminal organization is managed by different types of scheduling programmes which distinguish berth allocation, cargo arrangement and workforce scheduling. Although these three functions are separated in the programme, they are all connected and require simultaneous management. Programmes are helpful when planning port operations, but most of the decisions are nevertheless made by experienced professionals. Therefore, logistics processes on terminals are human centric, diverse, complex, flexible and valuable [1]. Diversity of types of cargo, parties involved and modes of transport cause complexity in logistics processes, thus reducing the probability of human error. Simultaneously, interconnection of several parties results in a more intricacy for an efficient management [2]. The aforementioned characteristics explain how much coordination between every operational step is needed when logistics processes are arranged.

The subsequent section of the paper describes export and import processes from the origin to the end point, the former starting at the terminal gate, i.e. upon vehicle arrival and ending upon loading of the vehicle onto the vessel. Contrarily to the export process, import commences with the vehicle on board the vessel and terminates with the vehicle leaving the gate. Additionally, both processes can be subclassified into truck or trailer export/import. The former refers to the movement of cargo within the port, assisted by vehicles, and in the latter case by cargo-handling equipment. Truck or trailer export/import complete a well-functioning cycle of logistics operations.

2.1. Export process

The pre-export process begins when a need for Ro-Ro transport arises. Particular orders for cargo transport are usually made online and particulars such as export country, import country, when the transport is needed, the type of cargo and contact information (usually e-mail) are specified. Within a certain time frame, logistics operators receive the order and enter it for future planning of export process. Logistics operators determine the exact route of transport and modes of transportation that will be used. In this case Ro-Ro cargoes can arrive either on trucks or trains and are transported by a Ro-Ro vessel to the port of destination. The next phase is the export process when Ro-Ro cargoes arrive at the terminal gate (see Figure 2).

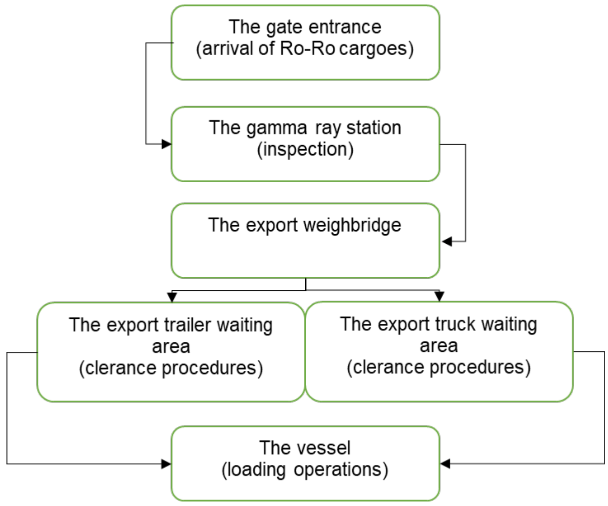


Figure 2 Illustration of an export process; Source [10]

Queues may occur at any point of terminal operation, for instance at the gate where paperwork is checked. If it is ascertained that the vehicle and/or cargo is in accordance with respective rules and regulations, they will be directed to proceed to the terminal area and after that to the gamma-ray station to undergo a security check. During the security checks, customs officers will perform a thorough visual inspection should they suspect any irregularities. Once the inspection has been completed and the vehicle found to comply with customs requirements, it is weighted at the weighbridge, so vehicles and other Ro-Ro cargo can safely be stowed. On the other hand, if it is found that the vehicle or any other Ro-Ro cargo does not comply with customs requirements, it is held on the terminal for further inspections. After that, the vehicle can make its way to the truck or trailer waiting area to await breaking-bulk. The trailer waiting area is designed for Ro-Ro cargo that needs special equipment for their further movement (e.g. trailers, containers, high and heavy cargoes). The truck waiting area is designed for different vehicles that can move by themselves. When a trailer is being shipped, a truck will leave it in the trailer waiting area to be further transported by tractors or MAFI. Once the ship arrives, unloading operations will precede loading operations. Rarely ship loading and unloading operations are held at the same time [13]. Drivers will be assigned to individual tractors and vehicles and will place them on designated positions onboard ship. All the aforementioned operations require precise planning to eliminate bottlenecks and ensure smooth operation.

Through the export process included parties are required to procure certain documents for successful transportation such as Bill of Lading, Certificate of Conformity, Certificate of Origin, Commercial Invoice, Export License, and Insurance Certificate. With the Certificate of Conformity exporter confirms that products are tested in accordance with import country. Certificate of Origin is declared at the customs office because the customs authorities calculate the duty rate depending on the origin country. Commercial Invoice simply proves the purchase and provides seller's and buyer's details. An Export Licence is a document that provides government compliance to export certain products to other countries. Furthermore, an Insurance Certificate is an essential document because it proves that Ro-Ro cargo, a high value cargo, is insured and potential loss can be covered. Nowadays, all aforementioned documents are in electronic form, hence the whole export process is less time consuming and fewer errors appear.

2.2. Import process

Comparable to the export process, the import process begins when goods need to be transported. In the case of import. the demand for goods arises in the destination country and implies a shortage of named goods in the country, so goods need to be imported. Imported goods can be intermediate or final goods. In the case of Ro-Ro transport, intermediate goods can be cars that are not fully equipped and need an additional upgrade or finishing.

Berthing and mooring of the ship mark the beginning of the import process, as illustrated in Figure 3.

The documents required for import are similar to those required for the export process. The only difference is that instead of the Export License, the Import License is procured, which serves as proof of the potential import to the specified country.

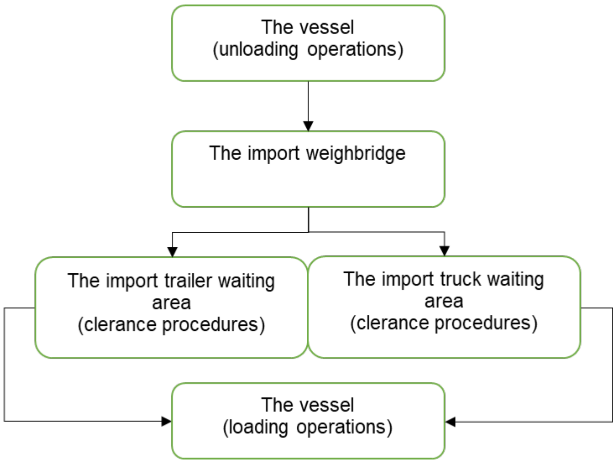


Figure 3 Illustration of an import process; Source [10]

Once the ship arrives and is cleared, and when the ramp is positioned safely, unloading operations can commence. An in-depth explanation of the stevedoring process can be found in further sections of this paper. Once a vehicle enters the terminal area, it is immediately directed to the weighbridge where weight is checked again [13]. The import process does not have the gamma ray station for the customs inspection because it is assumed that it has already been cleared in the port of origin [10]. As already stated, this accelerates the import process, and the terminal area is used for additional parking areas. Once customs operations are completed and paperwork checked, the vehicle can proceed from the waiting areas to the exit gate, i.e. leave the terminal.

3. PORT OPERATIONS IN RO-RO TERMINALS

Operations on a Ro-Ro terminal commence when each vessel is bound to be moored at the terminal or when each vehicle enters the terminal gate. Port operations require preliminary preparation, so each group of stevedores is assigned a different task, e.g. “lashers”, drivers, signalization crew, etc. When the plan is executed accordingly perils and congestion are minimized. Safe Ro-Ro operations are at risk from tides and waves, hence a berth must be able to withstand such conditions. This can be achieved by building locks or specially designed shore ramps. One of the features of Ro-Ro vessels is a small berthing area and expedient turnover. The Ro-Ro terminal is not used only for unloading, loading and storage of vehicles (common handling services), but it can provide workshops for technical services as well [9], where inspection of vehicles, quality control technical modifications and other services can be performed.

3.1. Berthing and stevedoring

Under berthing and stevedoring operations, processes such as berthing, mooring, cargo discharge and loading, unmooring and unberthing of a vessel and movement of cargo from or to the vessel and to or from a storage area are included [3]. Once the ship arrives and is secured in a safe position, breaking-bulk can commence. Since laytime begins once the ship is berthed, these present crucial points in the operation. The time used to berth, moor and lower ship's ramps is called operational time [11]. The operational time is more or less fixed and depends on the location of the berth, weather conditions and overall port characteristics.

When the vessel is safely moored, a ramp that can be either on the bow or the stern, is lowered and stevedoring can commence. Accordingly, stevedoring time commences and depends on the type of cargo. The first group of staff that goes onto the vessel are the so called "lashers" who unlash vehicles and other Ro-Ro cargoes that are bound for specified port of discharge. Simultaneously, the other group puts traffic cones, signal flags or lights and other signalization for safe operations. After every part of the vessel has been secured, the unloading crew can embark the vessel and, finally, unloading can safely commence. Generally, unloading operations are more abrupt, but while unloading, as well as loading, the driving speed and distance from other vehicles must be respected. While in cabin driving speed must be under 20 km/h and lowered to 5 km/h while on ramps or when turning. [18]. Only after discharge is complete, loading can commence.

The loading process starts when drivers pick up vehicles from the waiting area and proceed to the ramp. Before entering the vehicle, the designated driver must check the vehicle for possible damage and scan vehicle's barcode, RFID tag or Magnetic ID Card, as was described in previous sections of this paper. A clearly defined stowage plan considering the position, weight of the cargo and its port of discharge will dictate loading operations. When arranging the Stowage plan, height and weight of vehicles and bulk cargo should be considered. Usually, higher decks can accommodate lighter vehicles, such as cars. At the same time, lower decks are sturdier and higher so they can accommodate high and heavy cargoes, such as commercial, agricultural, and military vehicles, rail cars, motorboats, helicopters, elevators and escalators, pumps, energy generation equipment, paper reels, wood and steel products, etc. The LIFO (last in, first out) method is commonly employed on Ro-Ro vessels, especially when there is only one ramp for both unloading and loading. According to the Stowage plan, distance between parked vehicles must be minimal to maximize available space. Minimum distance between car doors should be 10 cm and between bumpers 30 cm [18]. The distances are extremely short so great care must be taken not to damage adjacent vehicles. Furthermore, the driver must be careful to leave as few driving signs as possible. The driver's responsibility, before leaving the vehicle, is to "put the vehicle in the right gear" and leave the car key inside the vehicle.

After vehicles are parked stevedores must undertake lashing of cargoes, i.e. securing the cargo with lashing equipment such as tensioners and chains in a safe manner to prevent it from shifting during transit. It is important to note that heavier vehicles and other bulk cargoes must be secured with steel chain lashings. Small openings on deck are used to secure the cargo. The cargo needs to be secured in such a manner to prevent it from moving during transport (see Figure 4), as this would present a risk to the safety and stability of the vessel and might cause it to capsize. To prevent lashings from coming loose, they are verified several times during transportation.

Figure 4 Proper vehicle lashing; Source [8]

After the cargo has been properly stowed, loading operations are finalized. Stevedores must take great care to collect all remaining lashing and store it in designated area on the terminal. They also need to gather previously set traffic cones, signal flags or lights and other signalization, and store them on the terminal. At this moment stevedoring time ceases and when the ramp is hoisted operational time commences.

3.2. Storage

It is safe to say that storage areas (i.e. large parking lots, multi-storey garages) in Ro-Ro terminals are the biggest weakness of Ro-Ro transportation. Most of the storage area is uncovered, excluding multi storey garages, but presence of high value cargoes (excluding cars) requires specially covered areas, such as simple sheds. Both parking lots and multi storey garages require large square footage and are a substantial investment. Another factor affecting the size of the parking lots is the need for the distance between vehicles to avoid potential damage. But, not only that, manoeuvring space is also needed for high and heavy cargoes. Ro-Ro terminals can be operated 24 hours, 365 days per year, so severe weather conditions and night conditions require well-lit parking lots and other types of storage areas, which act as buffers between land and sea transportation. It is advisable to reduce or absolutely eliminate storage, as it incurs additional costs, especially in case of delays [15]. In case storage time is used to upgrade the vehicle, for the purpose of increasing its value, then storage is not considered to be a cost.

Additionally, the location of storage areas determines the flow in the Ro-Ro terminal. Three layouts of parking spaces can be considered depending on the number of lanes and orientation: 1) parallel to the berth and spreading to the one side of Ro-Ro ramp (P configuration), 2) parallel to the berth but spreading to both sides of the ramp (M configuration) and 3) parking spaces perpendicular to the berth centred between two lanes of parking lots, facing the aisle in between (B configuration), as can be seen in Figure 5 [12].

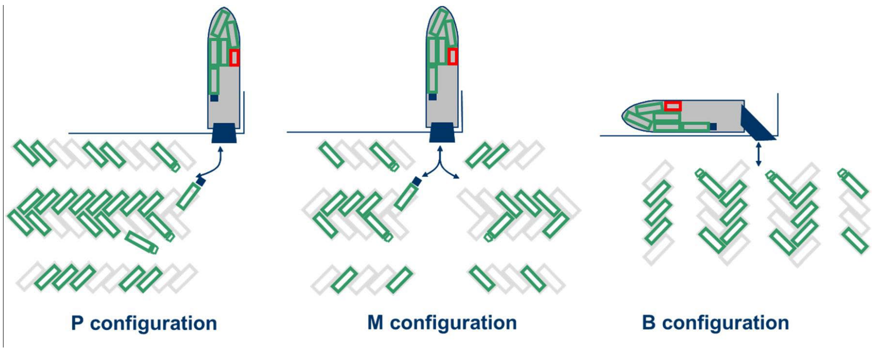


Figure 5 The layout of parking spaces; Source [12]

Storage areas or yard regions are divided into zones [5]. So, for instance, one part of the terminal is assigned only for cars while the other one is designated for different high and heavy cargoes. Division into zones simplifies loading and unloading operations, and overall functioning of the terminal. Every cargo unit is allocated according to the zone to which it belongs. Once allocated, storage space should not be relocated, because it causes unnecessary movement on the Ro-Ro terminal, thus leading to possible congestion. Also, every movement causes avoidable additional fuel consumption, making Ro-Ro terminals a place of increased exhaust gas pollution.

Another aspect of storage that needs to be considered is the storage of port machinery. In case of Ro-Ro terminals, the positive aspect is that special port cranes are not needed, but vast number of tractors, forklifts, reach stackers and trailers are used in everyday operations and need to be stored. In addition, smaller, special sheds are essential for storing traffic cones, signalization and other equipment required for stevedoring.

3.3. Delivery and receipt

The land part of transportation includes the delivery and receipt of cargo and vehicles [15]. The delivery process begins when the end customer orders a vehicle (sea-land part of the transportation), and receipt process begins when vehicles and other Ro-Ro cargo are bound for a sea voyage (land-sea transportation). Once end customer inputs a delivery request the vehicle is removed from stock and requested modifications are performed [17]. Afterwards vehicles are loaded onto truck trailers or railway wagons for further transportation to the end customer. Receipt covers a process since a point where vehicle arrives to the gate including paperwork check and customs operations when the vehicle is already positioned on the terminal. On a Ro-Ro terminal, a constant flow of vehicles should be enabled and queues on terminal stations should be reduced.

4. CONCLUSION

Ro-Ro technology, which originated in the 19th century and has expanded drastically after the Second World War, has proven to be a great competitor for container transport due to its many advantages, amongst which the elimination of cargo-handling equipment is the most significant one. It allows cargo to be loaded and unloaded quickly and without delays, leading to constant flow of cargo and thus eliminating idle time and possible bottlenecks. Another feature of a Ro-Ro terminal is its low-cost investment and the possibility of transition from and into any other type of terminal. Being economically feasible, it is accessible to many ports worldwide. Planning a Ro-Ro terminal must involve a study of the hinterland as well as the future demand, and its strategical positioning is crucial to maximise positive aspects. The positive aspects have increased its market competitiveness, and have consequently led to increased demand for Ro-Ro transport. Additionally, environmental friendliness and cost-efficiency of this type of transport technology have contributed to its expansion worldwide.

The import and export processes are oppositional in direction, so there is a slight difference between import and export procedures. However, both of these require a lot of paperwork to be completed. To reduce the workload and human intervention to the smallest degree possible, electronic forms are nowadays commonly in use. Ro-Ro terminals can further be enhanced by introducing Internet of Things (IoT) into its logistics services, thus eliminating manual labour and human intervention otherwise prone to making errors. In this way, the logistics process is simplified. Furthermore, scheduling programmes can help eliminate human error when planning port operations, so their further development is advised, as well as the implementation and development of barcode, RFID tag and Magnetic ID Card usage. Further research in the field of optimization of port operations and logistics processes in Ro-Ro terminals could lead to a reduction in cargo movement, thus lowering fuel consumption and providing better services to terminal users worldwide.

REFERENCES

[1] Amrou M´hand, M., Boulmakoul, A., Badir, H., Lbath, A.: A scalable real-time tracking and monitoring architecture for logistics and transport in RoRo terminals, Procedia Computer Science, Leuven, Belgium, 2019, Vol. 151, pp. 218-225, (ISSN: 1877-0509), DOI: 10.1016/j.procs.2019.04.032.

[2] Amrou, M., Boulmakoul, A., Hassan, B., Eddoujaji, M.: Process mining driven analysis -Model discovery: Case study of RoRo terminals, 8th edition of International Conference on Innovation and New Trends in Information Technology, Tangier, Morocco, 2019, p.p. 131-137, (ISBN: 978-9-98-113000-1), DOI: 10.475/123_4

[3] Amrou, M., Boulmakoul, A., Hassan, B.: On the exploitation of Process mining and Complex event processing in maritime logistics: RoRo terminals, International Conference on Innovation and New Trends in Information Systems, Marrackech, Morocco, 2018, (ISBN: 978-9920-35-479-4)

[4] Amrou, M., Boulmakoul, A., Hassan, B.: Process Mining towards Big data analytics in logistics environments: RORO Terminals, Conference: Business Intelligence & Big Data, Tanger, Morocco, 2018, Vol. RNTI-B-14, p.p. 331-332, (ISBN: 979-10-96289-08-0)

[5] Chen, X., Li, F., Jia, B., Wu, J., Gao, Z., Liu, R.: Optimizing storage location assignment in an automotive Ro-Ro terminal, Transportation Research Part B: Methodological, 2021, Vol. 143, p.p. 249-281, (ISSN: 0191-2615), DOI: 10.1016/j.trb.2020.10.009.

[6] Christodoulou, A., Raza, Z., Woxenius, J.: The Integration of RoRo Shipping in Sustainable Intermodal Transport Chains: The Case of a North European RoRo Service, Sustainability, 2019, Vol. 11, Issue 8, (ISSN: 2071-1050), DOI: 10.3390/su11082422

[7] Henesey, L., Lizneva, Y., Philipp, R., Meyer, C., Gerlitz, L.: Improved load planning of RoRo Vessels by adopting Blockchain and Internet-of-Things, Proceedings of 22nd International Conference on Harbor, Maritime and Multimodal Logistic Modeling & Simulation, Athens, Greece, 2020, p.p. 58-65, (ISSN: 2724-0339), DOI: 10.46354/i3m.2020.hms.009

[8] https://www.nauticexpo.com/prod/sec-bremen/product-31607-255894.html_(accessed on 13 May 2021)

[9] Jahte, N., Lütjen, M., Freitag, M.: Indoor Positioning in Car Parks by using Wi-Fi Round-Trip-Time to support Finished Vehicle Logistics on Port Terminals, IFAC-PapersOnLine, 2019, Vol. 52, Issue 13, pp. 857-862, (ISSN: 2405-8963), DOI: 10.1016/j.ifacol.2019.11.237.

[10] Keceli, Y., Aksoy, S., Aydogdu, V.: A simulation model for decision support in Ro-Ro terminal operations, International Journal of Logistics Systems and Management, 2013, Vol. 15, No. 4, p.p. 338-358, (ISSN: 1742-7975), DOI: 10.1504/IJLSM.2013.054896

[11] Morales Fusco, P., Sauri, S., Spuch, B.: Quality indicators and capacity calculation for RoRo terminals, Transportation Planning and Technology, Barcelona, Spain, 2010, Vol. 33, Issue 8, pp. 695-717, (ISSN: 1029-0354), DOI: 10.1080/03081060.2010.527179

[12] Morales Fusco, P.: Roll on-Roll of terminals and truck freight. Improving competitiveness in a Motorways of the Sea context, PhD. Thesis, Barcelona, Spain, 2016, p.p. 43-87

[13] Muravev, D., Rakhmangulov, A., Aksoy, S., Aydogdu, V.: Comparing model development in discrete event simulation on Ro-Ro terminal example, International Journal of Logistics Systems and Management, 2016, Vol. 24, No. 3, p.p. 283-297, (ISSN: 1742-7975), DOI: 10.1504/IJLSM.2016.076890

[14] Özkan E. D., Nas S., Güler N.: Capacity Analysis of Ro-Ro Terminals by Using Simulation Modelling Method, The Asian Journal of Shipping and Logistics, 2016, Vol. 32, Issue 3, pp. 139-147, (ISSN: 2092-5212), DOI: 10.1016/j.ajsl.2016.09.002.

[15] Paulić, M.: The Concept and Potentials of Ro-Ro Terminals for Providing Ro-Ro Services with an Overview of the Port of Bremerhaven, Bachelor's thesis, Faculty of Maritime Studies, University of Rijeka, Rijeka, 2020.

[16] Santos, T. A., Guedes Soares, C.: Short Sea Shipping in the Age of Sustainable Development and Information Technology, Routledge, Abingdon, UK, 2020, 1st Edition p.p. 89-140, (ISBN: 978-0-367-23242-9)

[17] Scholz-Reiter, B., Böse, F., Teucke, M., Piotrowski, J.: Integrated planning and control on Ro-Ro terminals, Proceedings of 7th International Workshop on Modelling & Applied Simulation, Amantea, Italy, 2008, p.p. 275-280, (ISBN: 978-1-62993-475-4)

[18] Shen, M., Yao, Y., Jiang, S., Ma, R., Wei, Y.: Research on the operation flow of commercial automobile Ro-Ro terminal, IOP Conference Series: Earth and Environmental Science, Qingdao, China, 2021, Vol. 692, 1. Energy Material and Power Grids, (ISSN: 1755-1315), DOI: 10.1088/1755-1315/692/2/022013

TRACK AND DEPTH CONTROL OF AUTONOMOUS UNDERWATER VEHICLE USING ADAPTIVE NEURAL NETWORKS

Viet-Anh Pham
PhD student – Ho Chi Minh city University of Transport
Ho Chi Minh city, Vietnam

Phung-Hung Nguyen
Maritime Academy - Ho Chi Minh city University of Transport
Ho Chi Minh city, Vietnam
E-mail: hung@ut.edu.vn

Van-Ty Le
Maritime Academy - Ho Chi Minh city University of Transport
Ho Chi Minh city, Vietnam

UDK 629.56(204.1): 004.4

Summary

This paper presents a track and depth control system for autonomous underwater vehicle (AUV) based on adaptive neural networks. The neural network controllers (NNC) can adapt their weights using an online training algorithm so that control outputs make AUV's heading and depth follow the desired set point. To make the AUV be able to follow a desired route a guidance algorithm is used to produce the necessary course and depth inputs of the NNC. The performance of the control and guidance system is experimented on computer simulations using Matlab. The simulation results are then analysed and studied to demonstrate the feasibility of the proposed control system.

Keywords: Autonomous Underwater Vehicle, Neural Network Controller, Online Training, Guidance Algorithm

1. INTRODUCTION

Since 1990 theory and applications of artificial neural networks on automatic control of marine vehicles have been proposed by many authors. Many achievements have been obtained. In 2009 authors in [10] and [13] introduced artificial neural networks to control heading and depth of an Autonomous Underwater Vehicle (AUV). B. Borvic et.al. (2001) studied on controlling AUV using artificial neural networks [1]. In this study [1] the controller performed accurate control task the movement of AUV with propulsion's dynamics and current. This controller consists of a conventional algorithm and adaptive artificial neural network. J.H. Li at.al. (2001) introduced a study on controlling AUV movement with an adaptive neural network controller [8]. In 2017 B. Geranmehr and K. Vafaee introduced a study on sliding mode hybrid adaptive neural network controller with robust parameters for AUV [2]. The authors used nonlinear control method that was able to cope with noises using an intelligent approximation technique for the uncertainties of AUV and environment. The authors used Radial Basic Function neural network to approximate unknowns and uncertainties of the dynamics.

In the same year of 2017 R. Cui et.al. presented a study on controlling AUV using adaptive neural network with nonlinear control inputs by intensive learning algorithm [4]. The paper introduced control of AUV in horizontal plane in the influence of environmental effects, the nonlinearities of inputs and AUV model. The adaptive neural network used 2 neural networks, critic and action ones to assess the quality of the controller at current time and compensate for uncertain dynamics. Compensating items are added by the authors to cancel nonlinearities of the control inputs. This adaptive neural network controller was verified via simulations. In 2018 J. Zhao introduced a study on predictive control using neural network for AUV with input signal delay technique [7]. In this study the controller performed track control task for AUV. In order to compensate for control input delay and perform track following task the author proposed a predictive control algorithm. A neural network was used to approximate nonlinear uncertainties of the AUV dynamics and from mutual affects of heading, pitching and heeling angles. The stability was proved using Lyapunov principle. The author then verified the proposed algorithm by simulations. In 2019 U. Ansari and A.H. Bajodah studied on AUV control using adaptive neural algorithm and dynamics inversion.

However study on the application of this filed for automatic control has not been popular in Vietnam. In 2017 authors in [3] proposed a decoupled control scheme for heading and depth of AUV using adaptive neural network. In this paper the authors proposed a control system using adaptive neural networks and a guidance algorithm to control AUV following a desired track in a horizontal plane and in case of depth change. Computer simulations are carried out to verify the performance of the control system.

2. NEURAL NETWORK CONTROLLER DESIGN

2.1. Adaptive Neural Network Configuration and Training

It is shown in [1] that, using the standard notations as follows, for $i, j \in N$

O_i the output of neuron *i*;

I_i the input of neuron *i*;

θ_i the threshold value of neuron *i*;

w_{ij} the weight of the connection from neuron *i* to neuron *j*;

$g(x)$ the activation function of a neuron;

O_i^d the desired output value of neuron *i* (for output neurons);

γ the learning rate,

the NN can be described by

$$I_i = \sum_{j\in N} w_{ij} O_j + \theta_i \text{,} \tag{1}$$

$$O_i = g(I_i) = g\left(\sum_{j\in N} w_{ij} O_j + \theta_i\right). \tag{2}$$

The goal is to minimize the following error

$$E = \frac{1}{2}\sum_{i\in N} e_i^2 \text{,} \tag{3}$$

where $e_i = O_i^d - O_i$ if *i* is output neuron.

And the adaptation algorithm for NN in [70] can be written as

$$\dot{w}_{ij} = g'(I_i)\frac{O_j}{O_i}\sum_{k\in N} w_{ki}\dot{w}_{ki} - \gamma g'(I_i) O_j e_i \text{,} \tag{4}$$

where $\dot{w}_{ij}$ is the increment of weights, $g'(I_i)$ is the derivative of $g(I_i)$ with respect to I_i.

Equation (4) describes Brandt-Lin algorithm for adaptation of weights in NN. Later, a NNC based on the Brandt-Lin algorithm was proposed in [1] where the simulation showed the effectiveness of the NNC, and some notes and conclusions were figured out.

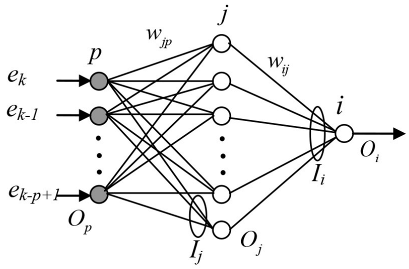


Figure 1 Configuration of the NNC

2.2. Neural Network Controller for AUV's Heading and Depth

2.2.1. NNC for Heading Control

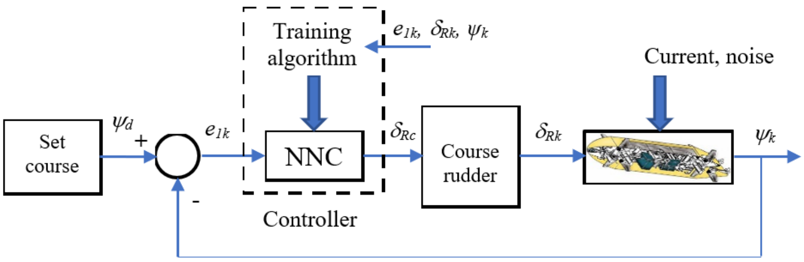


Figure 2 Configuration of the AUV heading controller

In the Figure 2, ψ_d and ψ are desired and actual heading of the AUV, e_{1k} is heading error; δ_{Rc} is rudder command of the NNC. Based on [3] the cost function for the neural network controller is written as

$$E_{1k} = \frac{1}{2}[\rho_1(\psi_k^d - \psi_k)^2 + \lambda_1\delta_{Rk}^2 + \sigma_1 r_k^2], \tag{5}$$

where δ_{Rk} and r_k are rudder angle and turning rate the AUV at *k* step; ρ_1, λ_1, and σ_1 are constants. These constants are weights of the components in the cost function.

The neural network was chosen as a multilayer feedforward neural network with single hidden layer. This neural network consists of 4 inputs neurons, 6 hidden neurons and 1 output neuron as described in [3]. The 4 input signals consist of e_{1k} and its delayed signals at k-1, k-2, k-3. Where w_{ij} are weights of output neurons, w_{jp} are weights of hidden neurons. Items *p, i* and *j* are number of neurons in input, output, and hidden layer correspondingly. Input signals of the controller are heading error of the AUV and its delayed signals. ψ_k^d is the desired heading and ψ_k is actual heading of AUV. The task of the controller is producing a proper rudder angle to minimize the cost function (5) by the following weight adaptation law:

$$\dot{w}_{1jp} = O_{1p}[\phi_{1j} sig(-I_{1j}) + \gamma_1 \cdot 0] = O_{1p}\phi_{1j} sig(-I_{1j}), \tag{6}$$

$$\dot{w}_{1ij} = \gamma_1 \cdot sig(I_{1j}) \cdot (\rho_1 e_{1k} + \lambda_1 \delta_{Rk} + \sigma_1 r_k) = \gamma_1 \cdot O_{1j} \cdot (\rho_1 e_{1k} + \lambda_1 \delta_{Rk} + \sigma_1 r_k). \tag{7}$$

Where $e_{1k} = \psi_k^d - \psi_k$ and

$$O_{1j} = sig(I_{1j}) = \frac{1}{1+\exp(-I_{1j})}, \tag{8}$$

$$I_{1j} = \sum_p (w_{1jp} O_{1p}) + \beta_{1j}, \tag{9}$$

$$\phi_{1j} = w_{1ij} \cdot \dot{w}_{1ij}. \tag{10}$$

2.2.2. NNC for Depth Control

In Figure 3 authors show the configuration of the AUV depth controller, where NNC uses input signals consisting of e_{2k} and its delayed signals at k-1, k-2, k-3 time steps and produces output signal δ_{Sc}. This output signal is then input to control the depth control planes of the AUV.

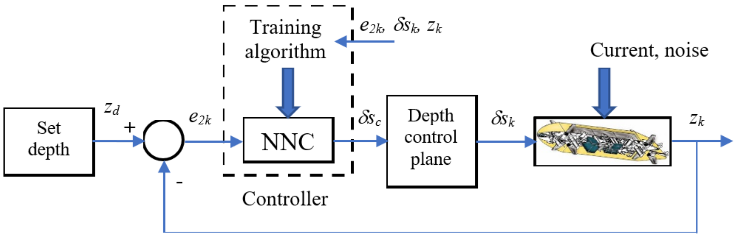


Figure 3 Configuration of the AUV depth controller

Similar to the study in [1] the cost function for depth control is proposed as:

$$E_{2k} = \frac{1}{2}[\rho_2 (z_k^d - z_k)^2 + \lambda_2 \delta_{Sk}^2 + \sigma_2 w_k^2 + \kappa_2 \theta_k^2], \tag{11}$$

where ρ_2, λ_2, σ_2, and κ_2 are constants; z_k^d, z_k are desired and actual depth; δ_{Sk} is the angle of depth control plane; w_k is vertical speed; and θ_k is the pitching angle of the AUV.

Weight adaptation laws in this case are:

$$\dot{w}_{2jp} = O_{2p}[\phi_{2j} sig(-I_{2j}) + \gamma_2 \cdot 0] = O_{2p}\phi_{2j} sig(-I_{2j}), \tag{12}$$

$$\dot{w}_{2ij} = \gamma_2 \cdot sig(I_{2j}) \cdot (\rho_2 e_{2k} + \lambda_2 \delta_{Sk} + \sigma_2 w_k + \kappa_2 \theta_k).$$

$$= \gamma_2 \cdot O_{2j} \cdot (\rho_2 e_{2k} + \lambda_2 \delta_{Sk} + \sigma_2 w_k + \kappa_2 \theta_k). \tag{13}$$

Where $e_{2k} = z_k^d - z_k$.

2.2.3. Track Control System for AUV

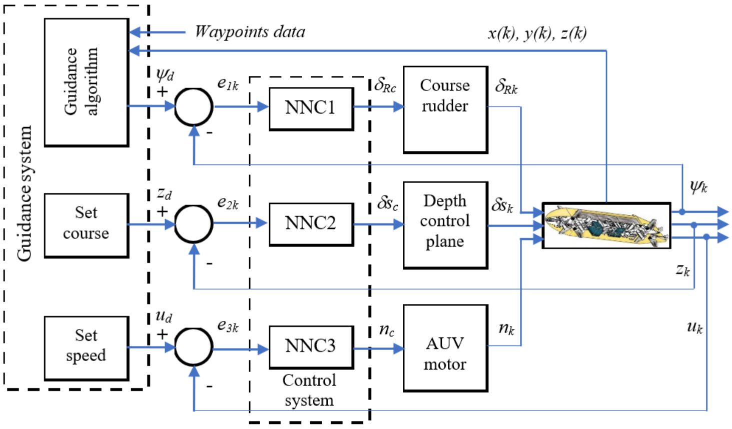


Figure 4 Configuration of the AUV track control system

Control an AUV following a desired track is usually applied for seabed exploring, search and rescue activities, searching for damages of underwater pipes, cables… These tasks are carried out considering that AUV move at a constant speed. The route in horizontal plane consists of the determined waypoints. The depth may be fixed or changed according to task requirement. In this paper the authors use Line-of-Sight (LOS) guidance algorithm [5] to control the AUV track the desired route.

Main task of the Guidance system is processing the desired and actual states of the AUV to produce desired heading signal. Then the controller makes the heading error (difference between actual and desired heading) become zero.

3. SIMULATIONS AND DISCUSSIONS

We set up the simulation on computer using Matlab and a nonlinear mathematic model of NSP AUV II (Figure 5) [5]. Main parameters and mathematic model of the NSP AUV II are presented in [5]. ρ_1, λ_1, and σ_1 are 0.5, 0.1 and 0.2; ρ_2, λ_2, σ_2, and κ_2 are 0.2, 0.1, 0.2 and 0.01.

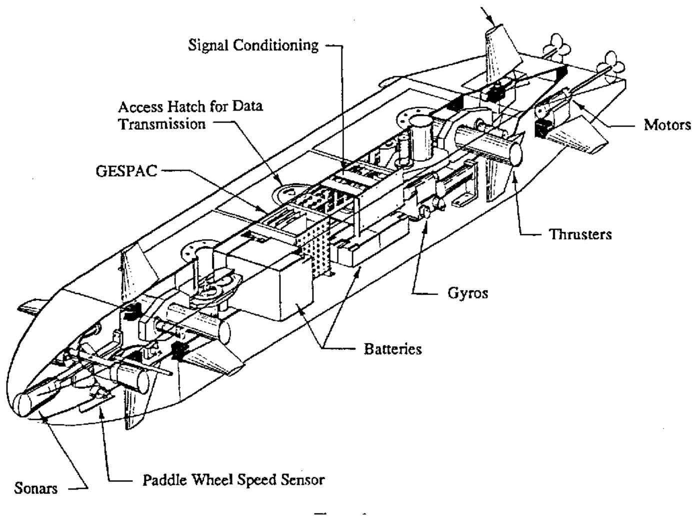


Figure 5 NSP AUV

- Simulation 1: Control AUV following square route, no change of depth, no current.

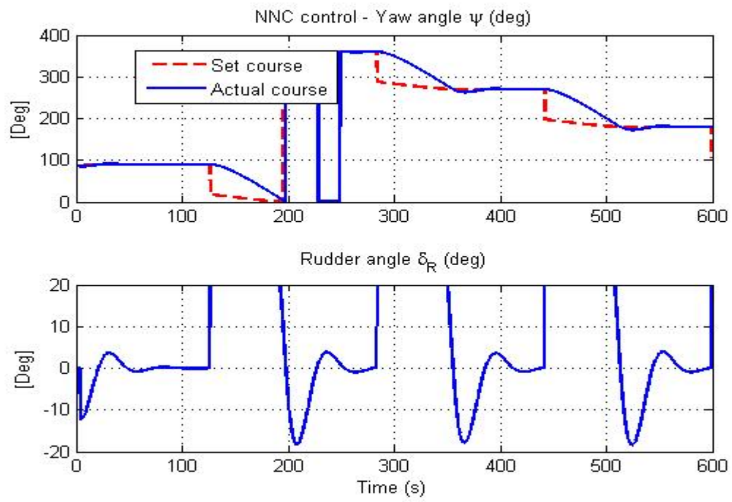


Figure 6 AUV heading response of simulation 1

Figure 6 shows on the upper graph the set course and actual course of the AUV controlled by NNC in simulation 1. The lower graph is rudder response of the NNC.

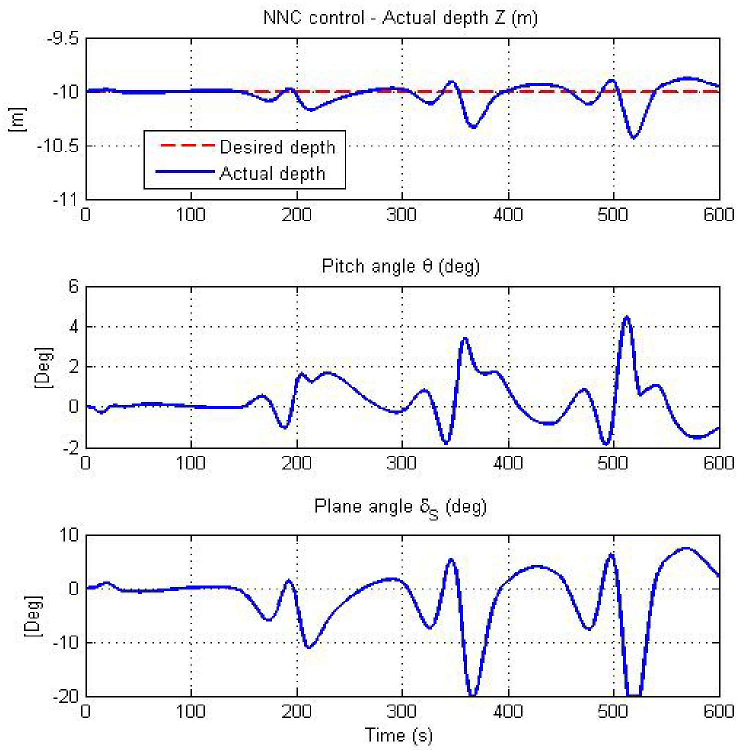


Figure 7 AUV Depth response of simulation 1

Figure 7 shows the depth control response of simulation 1, where the upper graph is desired depth and actual one; middle graph is pitch angle of the AUV; lower graph is plane angle response of the AUV.

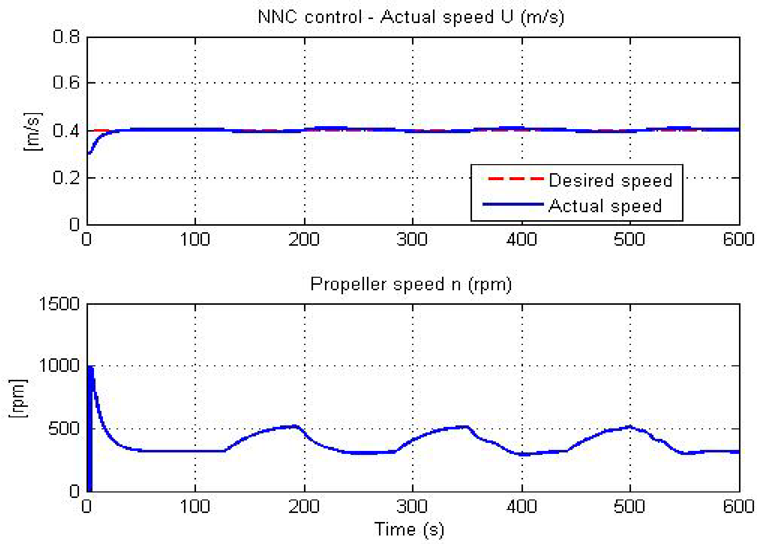


Figure 8 AUV speed response of simulation 1

Figure 8 shows the speed control response of the NNC, where the upper graph is desired speed and actual speed; the lower one is speed of the propeller by NNC.

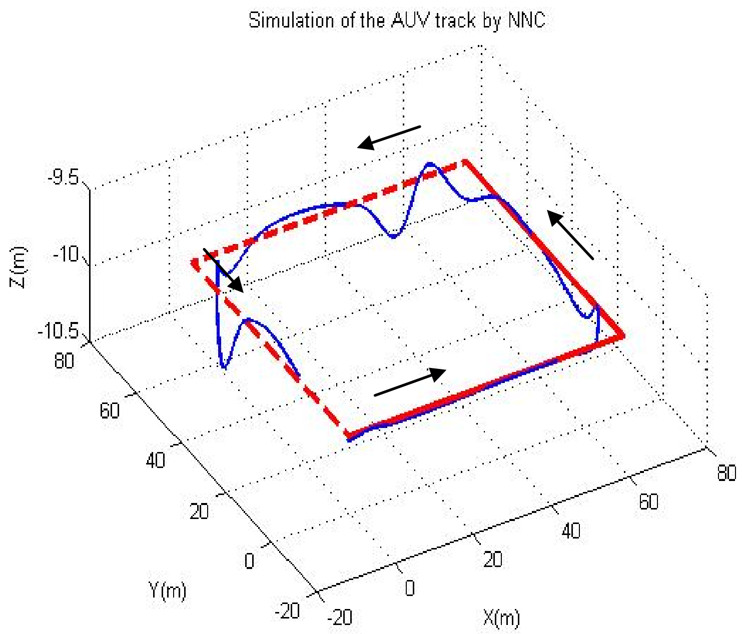


Figure 9 AUV track of simulation 1

In Figure 9, the route of the AUV consist of waypoints (0,0,10), (70,0,10), (70,70,10) and (0,70,10). This means AUV moves in a square route at a desired depth of 10m.

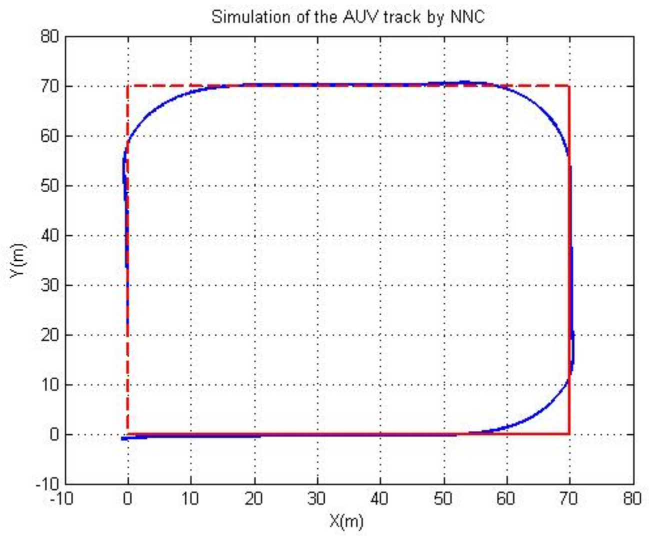


Figure 10 AUV track on vertical plane of simulation 1

Figure 7 and Figure 9 show the complicatedly mutual affect of course and depth while AUV change its course. The depth fluctuated.

- Simulation 2: Control AUV following square route, depth changed, no current.

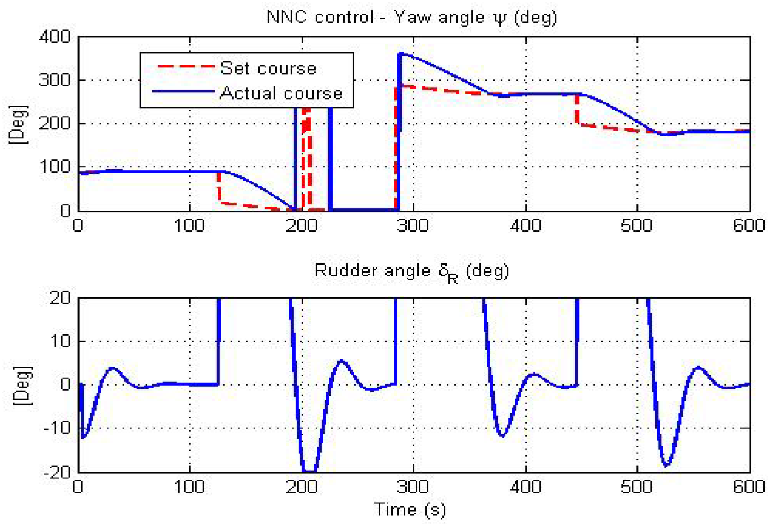


Figure 11 AUV heading response of simulation 2

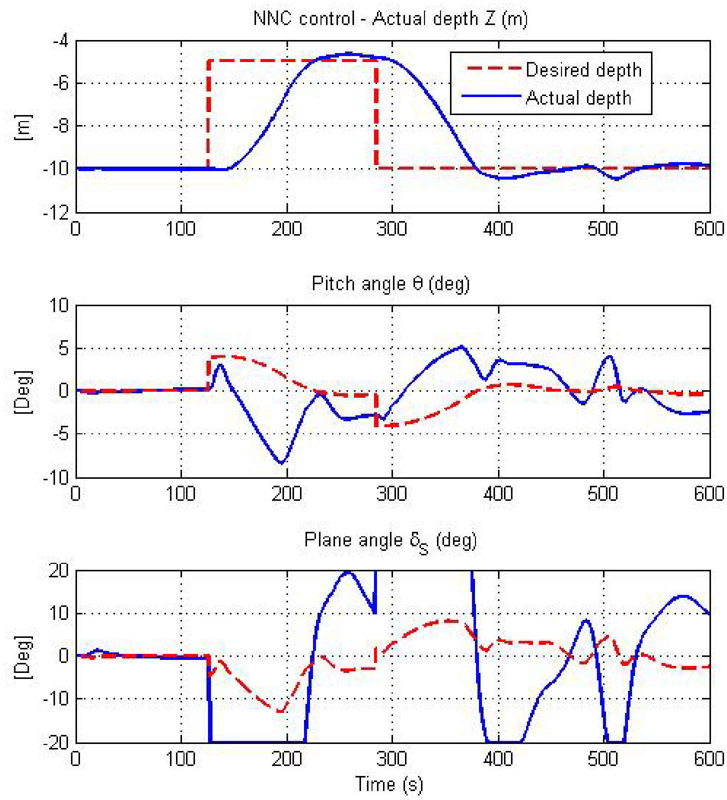


Figure 12 AUV Depth response of simulation 2

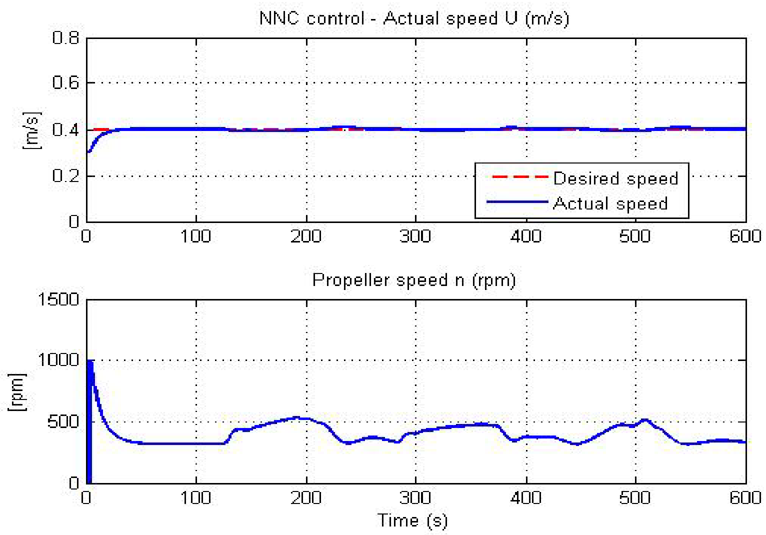


Figure 13 AUV speed response of simulation 2

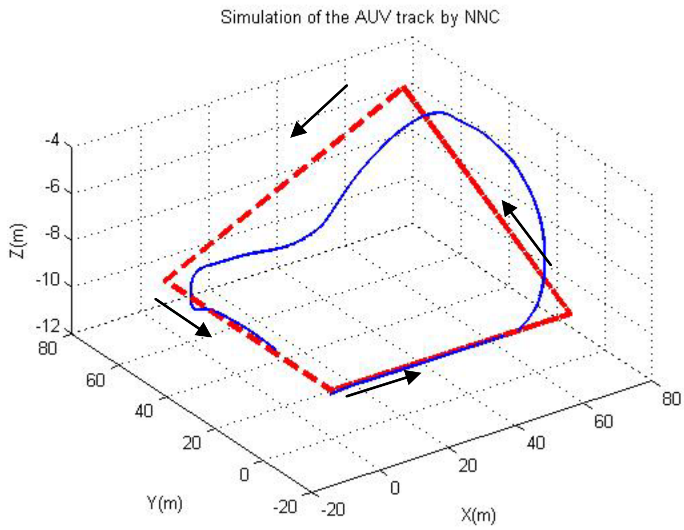


Figure 14 AUV track of simulation 2

In Figure 14, the route of the AUV consist of waypoints (0,0,10), (70,0,10), (70,70,5) and (0,70,10). This means AUV moves in a square route in the horizontal plane but the depth at the 3rd waypoint changes to 5m.

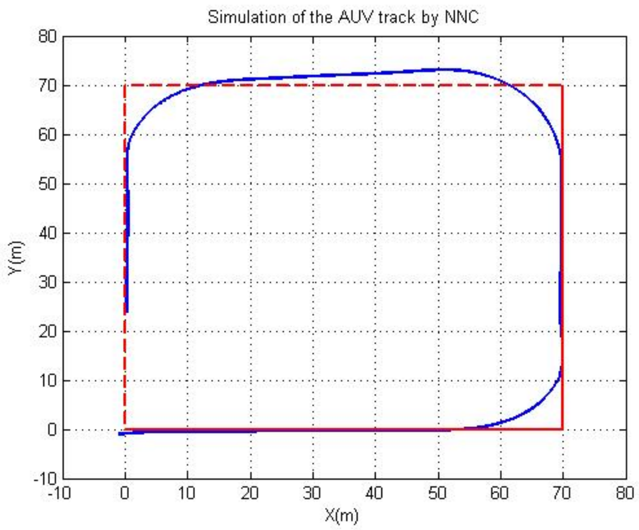


Figure 15 AUV track on vertical plane of simulation 2

In this simulation, the depth of the 3rd waypoint is 5m instead of 10m of the Simulation 1. Fore depth control plane is controlled by a DP controller with minimum gain to support only. During individual segment of the route the AUV followed the horizontal route and actual depth can reach the desired figure.

- Simulation 3: Control the AUV following zig-zag route without the effect of current and depth unchanged.

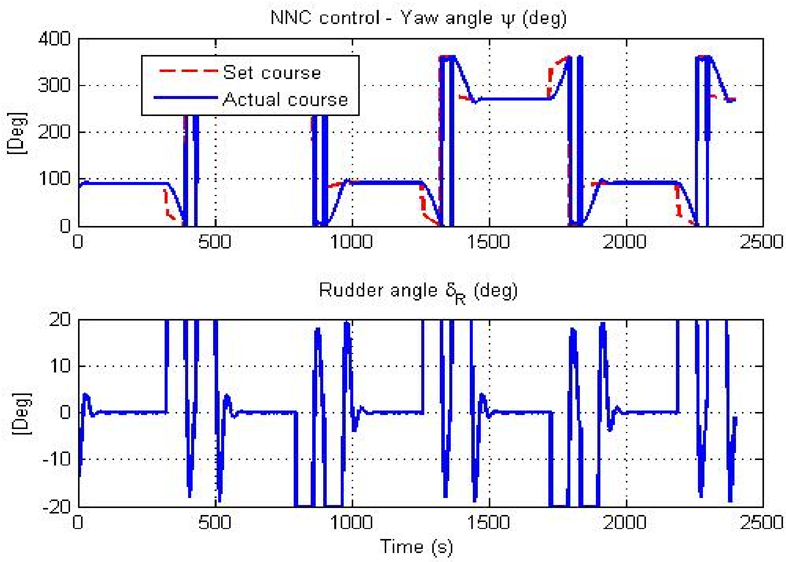


Figure 16 AUV heading response of simulation 3

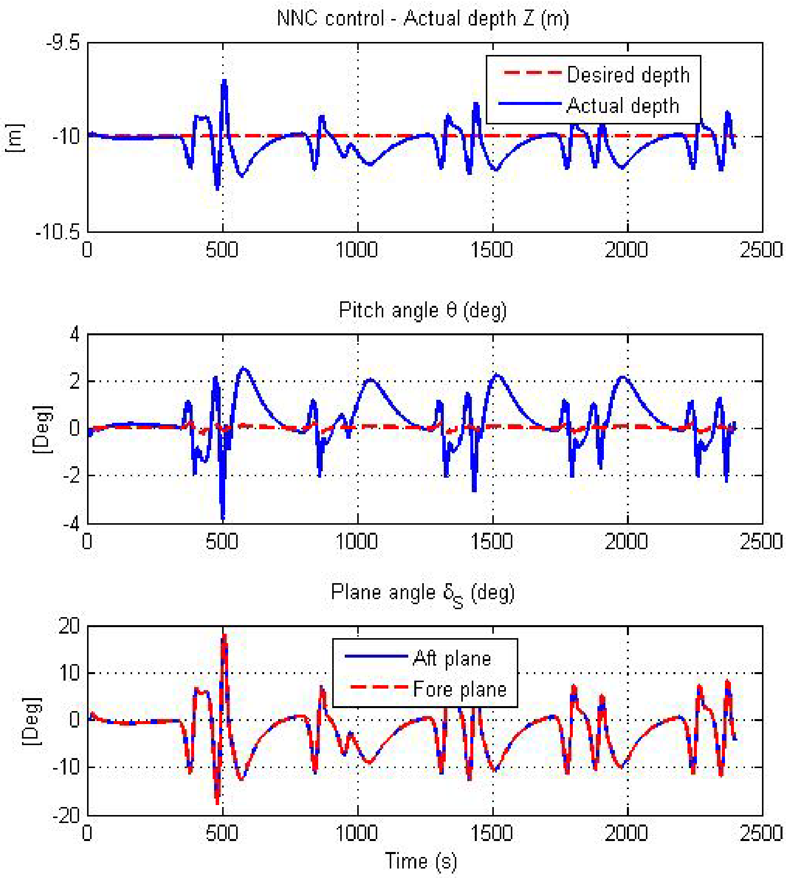


Figure 17 AUV Depth response of simulation 3

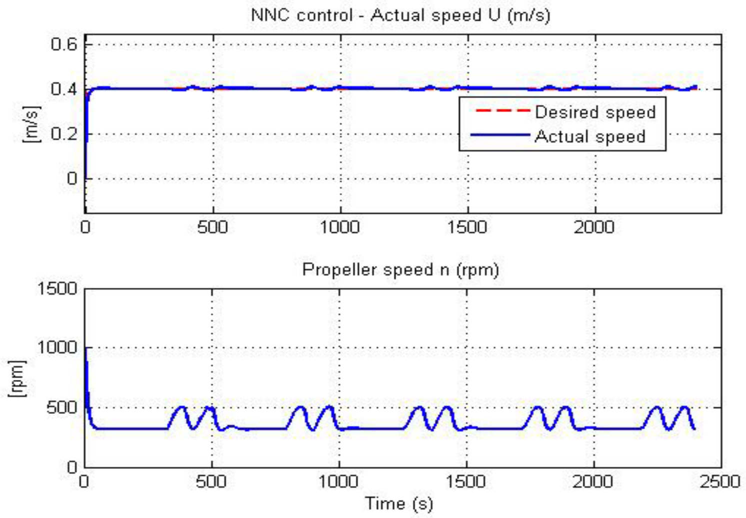


Figure 18 AUV speed response of simulation 3

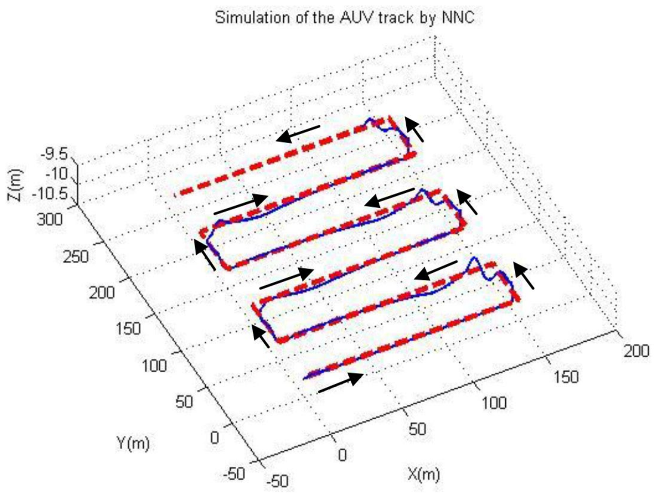


Figure 19 AUV track of simulation 8

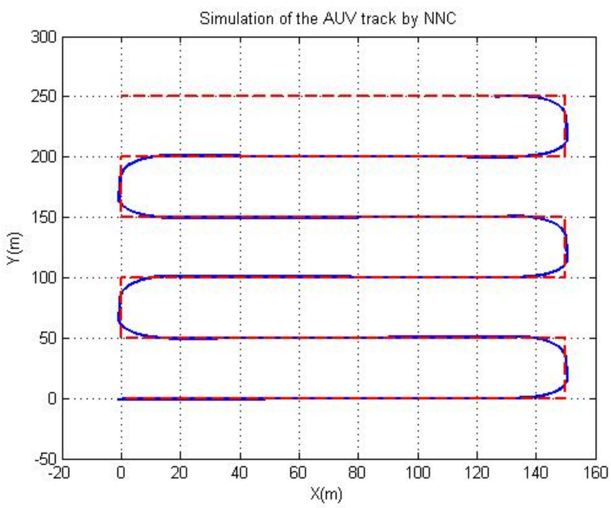


Figure 20 AUV track on vertical plane of simulation 3

This is one of the complicated navigation of the AUV with zig-zag route applied for seabed surveying, exploring or search and rescuing activities (Figure 18). The desired course on each segment may be LOS, course along two current waypoints or course between ship's current position and current destination waypoint. In this study we select LOS course as the desired one. NNC controller is used for both course rudder and forward depth control planes of the NSP AUV II.

- Simulation 4: Control UAV following zig-zag route under influence of current, depth stayed unchanged.

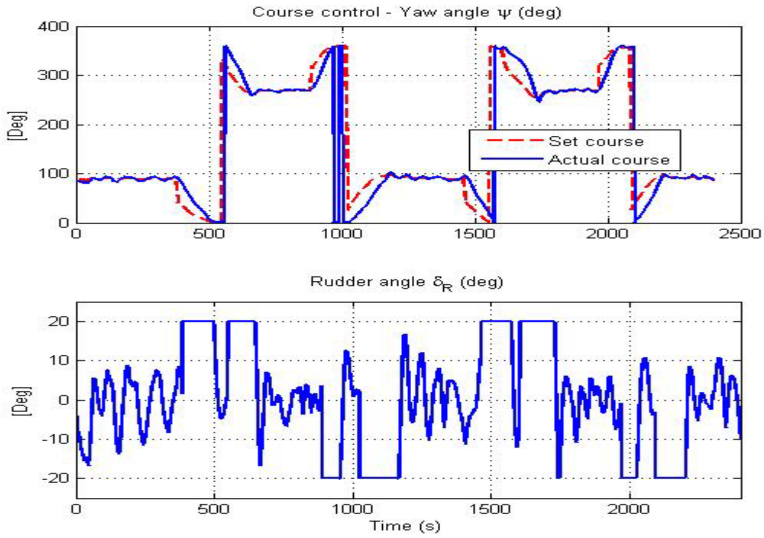


Figure 21 AUV heading response of simulation 4

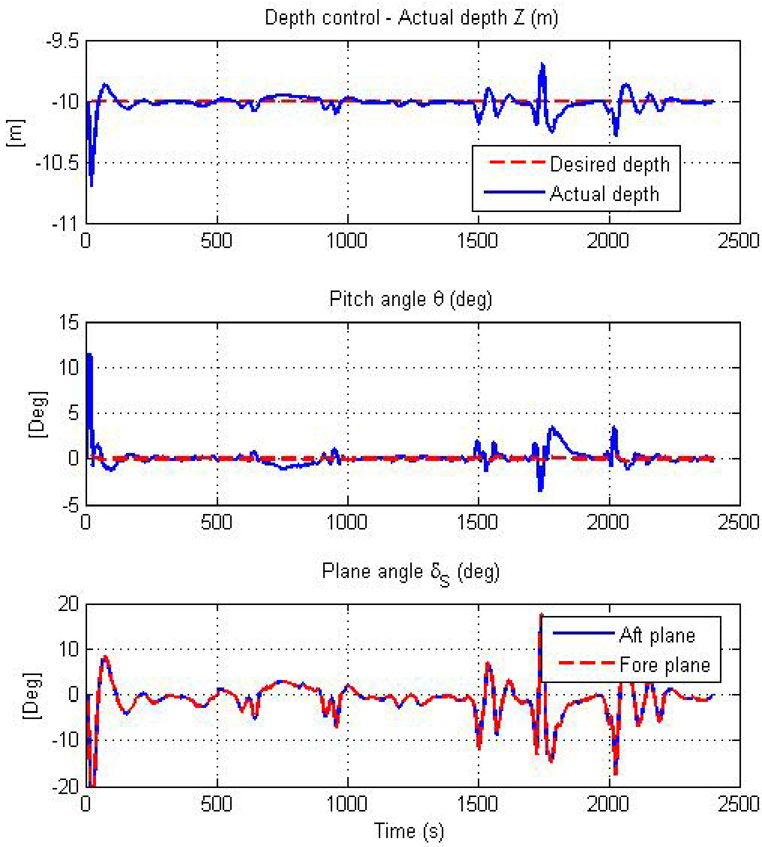


Figure 22 AUV Depth response of simulation 4

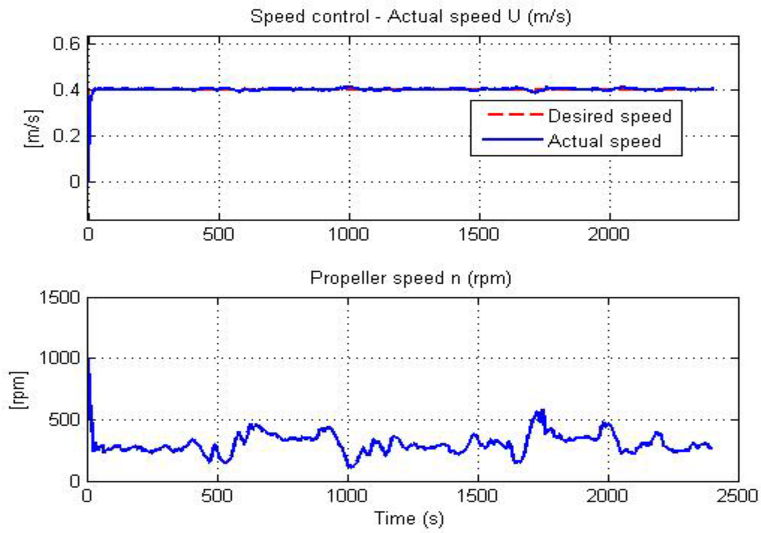


Figure 23 AUV speed response of simulation 4

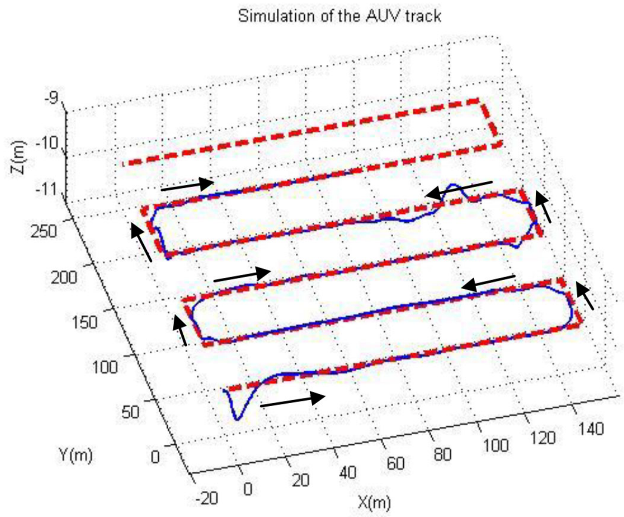


Figure 24 AUV track of simulation 4

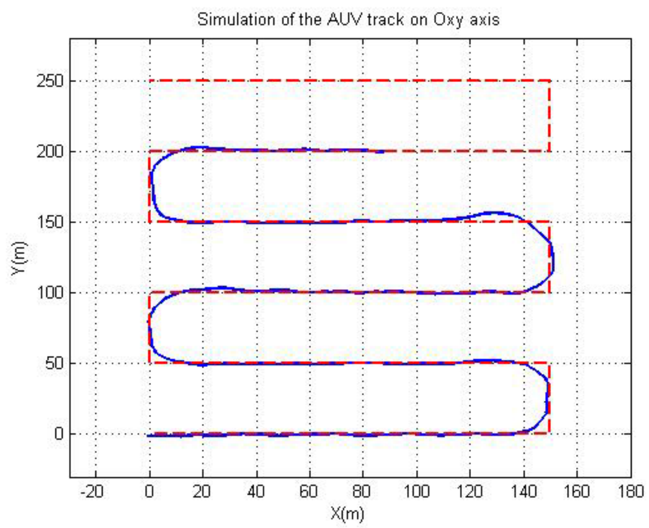


Figure 25 AUV track on vertical plane of simulation 4

In Simulation 4 current made course and position of AUV move and change. The depth also fluctuated but the AUV's position was still stable around horizontal plane.

3. CONCLUSION

In this study we developed an NNC that can control AUV depth and course effectively. The NNC was based on adaptive neural network which is able to be updated online. The NNC can be used with a guidance algorithm to control the AUV to follow a route of waypoints and maintain the desired depth. We presented the feasibility of using the NNC to control with online adaptive algorithm in controlling AUV with strong nonlinear characteristics.

Computer simulations were carried out to demonstrate the feasibility and effectiveness of the proposed NNC. The AUV can track a desired route in horizontal plane and change it's depth as required at a manoeuvring speed. In next study we will add items of sea current to the working environment of the AUV to adjust and improve the control ability under the external effects.

REFERENCES

[1] Bruno Borvic, Ognjen Kuljaca and Frank L. Lewis: Neural Net Underwater Vehicle Dynamic Position Control, Proceedings of the 9th Mediterranean Conference on Control and Automation, 2001.

[2] Behdad Geranmehr, Kamran Vafaee: Hybrid Adaptive Neural Network AUV Controller Design with Sliding Mode Robust Term, International Journal of Maritime Technology, Vol.7 (2017), pp.49-55.

[3] Chau Giang Nguyen, Viet Anh Pham, Duy Anh Nguyen: Heading and Depth Control of Autonomous Underwater Vehicles via Adaptive Neural Network Controller, AETA 2017-Recent Advances in Electrical Engineering and Related Sciences, ISSN 1876-1100 / ISSN 1876-1119 (electronic).

[4] Cui, R., Yang, C., Li, Y., and Sharma, S.: Adaptive neural network control of auvs with control input nonlinearities using reinforcement learning. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 47(6), 1019–1029 (2017).

[5] Fossen, T.I.: Marine Control Systems: Guidance, Navigation and Control of Ships, Rigs and Underwater Vehicles. Marine Cybernetics, Trondheim, Norway. ISBN 82-92356-00-2 (2002).

[6] GN Roberts & R Sutton (editors): Advance in Unmanned Marine Vehicles, IEE Control Engineering Series 69 (Series editors: Professor D. Atherton & Professor S. Spurgeon).

[7] Jiemei Zhao: Neural Network Predictive Control for Autonomous Underwater Vehicle with Input Delay, Journal of Control Science and Engineering Volume 2018, ID 2316957.

[8] Ji-Hong Li, Pan-Mook Lee, Sang-Jeong Lee: Motion control of an AUV using a neural network adaptive controller. Proceedings of the 2002 International Symposium on Underwater Technology, pp.217-221, 2002.

[9] Nguyen Phung Hung, Artificial neural networks – Applications in controlling marine vehicles. Science and technology Publishing house (2013), Vietnamese book.

[10] Nguyen Phung Hung, Vo Hong Hai: Controlling course and depth of autonomous underwater vehicles using adaptive neural network. Journal of maritime science and technology, No.18, 06/2009, pp.32-36 (ISSN 1859-316X) (in Vietnamese).

[11] Sabiha Wadoo & Pushkin Kachroo: Autonomous Underwater Vehicles (modelling, control design, and simulation), printed by (CRC) CRC Press Taylor & Francis Group (2011).

[12] Uzair Ansari, Abdulrahman H. Bajodah: Autonomous Underwater Vehicles Attitude control using Neuro-Adaptive Generalized Dynamic Inversion¸ International Federation of Automatic Control online 52-29 (2019), pp. 103-109.

[13] Vo Hong Hai, Nguyen Phung Hung: Controlling course of autonomous underwater vehicles using adaptive neural network. Journal of transport 08/2009, pp.39-41 (ISSN 2615-9751) (in Vietnamese).

BOOST PRESSURE MODIFICATION IN DUAL-FUEL CI CONVERTED ENGINE (CNG-DIESEL) AS A METHOD OF KNOCK REDUCTION[1]

Filip Polak
Institute of Motor Vehicles and Transportation
Faculty of Mechanical Engineering
Military University of Technology
Warsaw, Poland
E-mail: filip.polak@wat.edu.pl

UDK 629.5:621.43
662.7

Summary

Recently most Diesel engines are turbocharged, which tends to increase amount of delivered air. Increased amount of compressed air results burning much more fuel, increases total energy release, power output, engine thermal load, etc. This type of charging system works properly with compressed ignition engines powered with Diesel fuel. Introducing natural gas directly to the engine intake manifold when the Diesel engine is operating in dual-fuel mode, especially when high Diesel-to-gas exchange ratio is reached, cause some problems. The extra portion of gaseous fuel is added into overall volume of compressed air but because burning parameters of Diesel fuel and natural gas differ, this modification lead to the engine pressure increase to the point where knock occur. This study presents the methods of marginalize the knock phenomena caused by increased pressure coming from turbocharger and as a result, sustain high Diesel-to-gas exchange ratio with respect to the engine performance and with minimum engine conversion. Because presented dual-fuel retrofit system interfere with original engine map and engine parameters, changing requirements that may take much effort by engine such as controllable pressure reduction in the inlet system of a turbocharged engine, require pressure monitoring and pressure adaptation in respect to engine parameters and to avoid engine errors and malfunction. Pressure management of the engine may be executed in a different ways. This article presents methods, which can affect the engine boost control with respect to the dual-fuel mode and fuel exchange ratio.

Keywords: Dual fuel engine, boost, CNG, engine conversion

1. INTRODUCTION

Gas market is fastest developing fuel market on the World. Presently energy consumption in transportation sector depends on crude oils. This lead to, despite other aspects, increased engine emission or use other less pollutant fuels. This trend lead to introducing more cost-effective alternative energy sources on the market such as natural gas (NG). This technology is mature and use of NG in transportation is well known due to use of compressed natural gas (CNG) and liquefied natural gas (LNG) solutions broadly. NG is more and more often used which lead to increased demand for this energy source. This trend can be observed even in maritime sector. Inland, maritime and offshore transport tighten up environmental regulations and this leads to invest in gas powered watercrafts opposed to expensive scrubber installations. Mediterranean Sea is under Sulphur Emission Control Area (SECA) regulations and

[1] The publication was created as a result of work under: Poland Republic, National Centre for Research and Development, Military University Technology; Name of the competition: Ścieżka dla Mazowsza; Agreement No. MAZOWSZE / 0123 / 19-00; Subject: "Innovative ecological CNG installation for diesel engines limiting the emission of harmful exhaust components together with a mobile diagnostic platform."

Natural Gas enable to fulfil the requirements that are mandatory from January 1st 2020. Technology that use natural gas seems to be some kind of a bridge technology on the route to net zero emissions by 2050 [1], but presently LNG installations helps to decrease sulphur from 3,5% to 0,5%. Natural gas can be met also in railway logistics to power trains by LNG. There are many countries that invest in natural gas for powering trains (Russia, Estonia) [2]. Example of such solution is Florida East Coast Railway (US) where train powered with LNG operates on Jacksonville – Miami railroad.

2. GAS ENGINES

There are basically two types of gas engines:

1) „SING" (Single Ignition Natural Gas),
2) dual fuel engines.

SING engines are designed from beginning to operate on natural gas: compressed or liquefied. In dedicated engine which is spark ignited (SI) engine, efficiency is lover what might cause lower emission reduction [3, 4]. In such solutions, knock phenomena is controlled similarly like in traditional spark ignition engines.

Compressed ignition engines can be feed up by natural gas in different ways. Most popular solution on the market in dual fuel engines is so called Diesel-gas. Those engines are mostly converted from Diesel only to dual fuel engines. A principles of operation are similar to the 4th generatiion of LPG installation. Diesel oil is injected into combustion chamber with use factory installation (without modification of Electronic Control Unit – ECU). Additional gas dose from gas injectors is directly introduced into inlet manifold. Burning process is iniciated by self-ignition Diesel fuel and due to presence of natural gas, Diesel specific fuel consumption is decreased without decreasing engine power [5, 6]. Complete exchange for natural gas do not occur. Gas added to the fuel mixture become a burning catalyzer and affect effective use of Diesel oil. Dual-fuel solutions can use compressed ignition engines with up to 90-95% of gas and Diesel oil as a pilot dose to initiate ignition. As an example, such solution is shown on figure 1. Because compressed ignition engines vary from spark ignition parameters, when converted to the dual-fuel operation, a set of parameters must be considered to run properly [7].

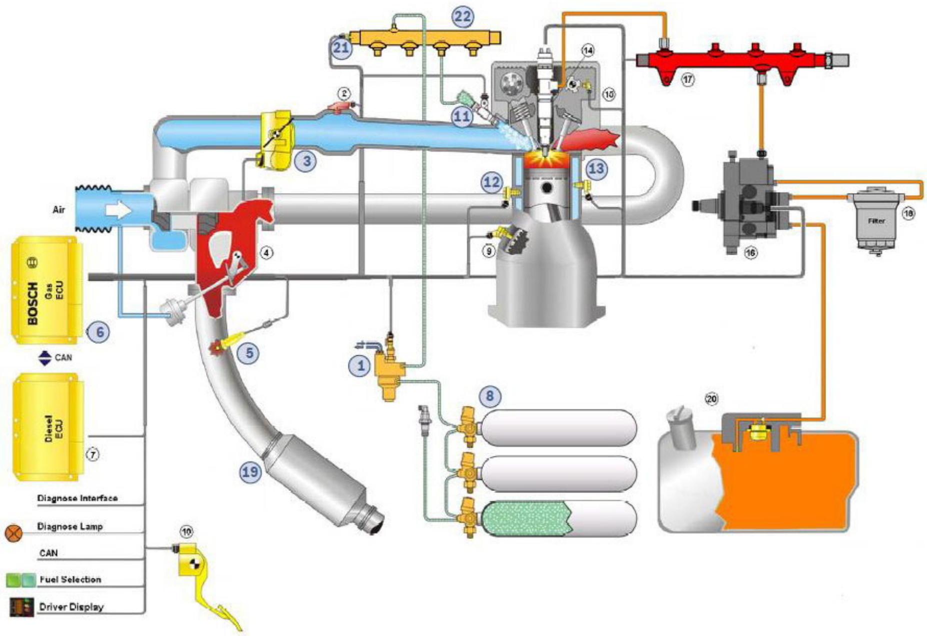


Fig. 1 A diagram of Bosch Dual Fuel system: 1 – gas pressure regulator, 2 – air pressure and temperature sensor, 3 – throttle, 4 – turbocharger's release valve, 5 – oxygen sensor, 6 – CNG controller, 7 – diesel oil controller, 8 – CNG tanks, 9 – engine speed sensor, 10 – gas pedal, 11 – CNG injector, 12 – knock sensor, 13 – engine temperature sensor, 14 –

diesel oil injector, 15 – engine phase sensor, 16 – high-pressure pump, 17 – Diesel common rail, 18 – fuel filter, 19 – oxidation catalyst, 20 – diesel oil tank, 21 – gas pressure and temperature sensor, 22 – CNG fuel rail

Source: [8]

3. KNOCK PHENOMENA

Knock is very complicated phenomena causing an abnormal work of an combustion engine. Ca from 2002 all new spark ignited cars has to be equipped mandatory with knock combustion sensor (fig. 2). This sensor correct spark advance to eliminate knock. The knock occurs when fi. weak quality of fuel is used. In normal conditions, fuel mixture is burned from spark in SI engine and flame is propagated through whole combustion chamber with constant speed of 30–60 m/s. This lead to achieve high pressure just couple of degrees after top dead centre (TDC). When spark occurs later, piston is closer to TDC and finally pressure is lower because piston position creates higher volume than only combustion chamber volume.

When spark occur sooner, fuel with weak quality is starts to burn abnormally and that cause higher load coming from arising pressure and piston compression stroke position. When knock occurs, fuel mixture starts to burn not only from spark but acting like a compressed ignition, but with multiple bonfires.

Figure 2 Knock sensor on a converted Diesel engine

Source: Author’s archive

At the figure 3 results of spark advance while normal work and when knock occurs can be seen. Fuel mixture starts to burn sooner than required and with higher speed, higher than sound speed. We can recognize this phenomena as a metallic sound coming from engine or under the car bonnet [5, 7].

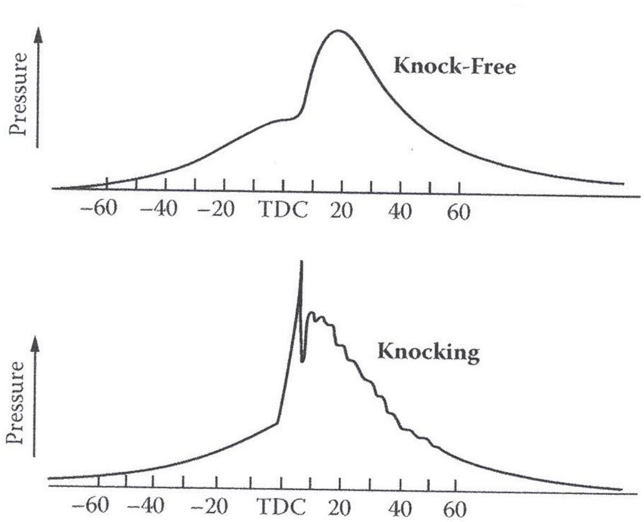


Figure 3 Pressure time development records for a dual-fuel engine when operating on methane under knock-free and knocking conditions

Source: [7]

The consequences of this phenomena can be very serious for the engine. Knock can burden mechanically and thermally elements of the engine such as pistons or connecting rods. Other symptom of knock is engine performance decrease.

Parameters that can affect knock occurring and its intensity, mostly in spark engines, can be described as a [5, 6, 7, 9]:

1) compression ratio,
2) boost pressure,
3) shape of combustion chamber,
4) spark advance,
5) fuel mixture,
6) dimensions of cylinder,
7) number of cylinders,
8) engine and engine head material,
9) crankshaft speed,
10) engine load,
11) thermal status of the engine,
12) exhaust resist,
13) fuel mixture preparation.

A increased compression ratio cause increasing of pressure during combustion process and increase the temperature during ignition. This lead to knock. If the compression ratio is increased, also octane number of the fuel must be increased.

Shape of combustion chamber is determined mostly by spark plug location, which had to be placed close to the hottest part of this chamber – area of outlet valve. This minimize possibility of combustion caused by contact with hot surfaces. That is why cooling system must drain heat evenly.

Spark advance increasing lead to knock occurring, when fuel mixture is not compressed appropriately during combustion process. The answer for this problem is to increase octane number of the fuel or decreasing spark advance which is corelated with engine speed – burning speed is almost equal and higher engine rotation speed require sooner spark occurring. If the engine is equipped with knock sensor and knock occurs, engine controller is decreasing spark advance. This type of correction lead to performance decrease or fuel consumption arise. This is possible only when converted Diesel engine is equipped with knock sensor.

Fuel mixture composition is monitored by oxygen sensor. Lambda sensor present in engine, keep air to fuel ratio $\lambda=1$ (exhaust gases composition) and this decrease the possibility to knock occur. Diesel dual fuel engines have to deal with this problem. Air to fuel ratio during compressed ignition reach $1.1< \lambda<1.65$, when introducing natural gas.

This list do not cover final parameters that can cause knock. Despite overmentioned main parameters, a lot of others, with minor impact, can occur. One of them is for example oil performance. If user delay oil change, this may occur in higher concentration of carbon deposits at the chamber walls and spark plugs or injectors can work inappropriate. The basic rule is to feed engine with fuel with good quality, without contaminations and with high octane number.

4. KNOCK REDUCTION

Knock in engine cannot be eliminated permanently, but there are many solutions to minimize this phenomena. Taking into consideration parameters described in chapter three of this paper, in dual-fuel converted engines, only couple of them are economically possible to adopt. For converted engines it is very common that second injection system is added and some minor changes in engine equipment and control system are made. Except parameters that are hardly to improve like a shape of the combustion chamber or engine head material, changes that are economically acceptable, when Diesel engine is converted to the dual-fuel, in most cases are:

1) fuel replacement ratio,
2) gas injection advance,
3) boost pressure.

Fuel replacement ratio is important parameter, because we can’t change the octane number of methane, assuming we have high quality gas, and the only way is to change percentage replacement between Diesel fuel and natural gas.

Gas injection advance can be made with respect to inlet valve opening in converted engines, if we assume that during conversion original Diesel injectors remain. Diesel converted engines have gas injectors placed next to the engine block intake duct which make them indirect gas injection engines (fig. 4). This lead to situation when time window, when gas injector can deliver fuel to the engine cylinder is short and gas dose must be introduced to the combustion chamber before valve is closed.

Last parameter, which is subject of this article, is boost pressure reduction. Most Diesel engines are turbocharged which increase their power when more air (and oxygen inside it) can combust with more fuel. When converted engine is equipped with additional gas injection system, extra amount of fuel volume is introduced inside the combustion chamber. Diesel engines are quality controlled which mean that into this same amount of air, different amount of fuel is introduced and this affect final fuel mixture composition. If during operating on natural gas this medium is added to the introduced air, power of the engine can increase because of increased amount of energy delivered to combustion chamber. Because compression ratio in Diesel engines is mostly higher than in spark engines, possibility of knock occur is higher. Into this mass of air, extra mass of natural gas is injected and pressure arise moving to the compression area where knock can occur.

Figure 5 shows data from the gas controller software. We can see the percentage replacement of the Diesel fuel to CNG with marked area where knock occurs during engine tests. Replacement line is set as close as possible, because greatest power lie down close to the knock area.

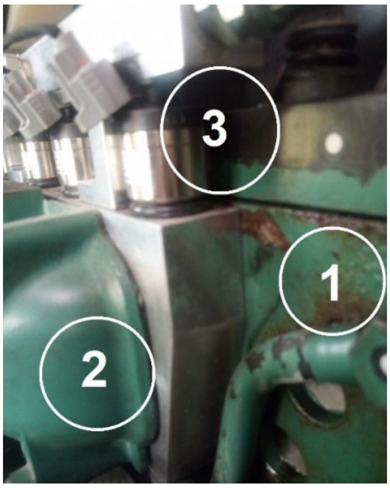


Figure 4 Example of gas injectors placed on a converted Diesel engine: 1 - engine block, 2 - intake manifold, 3 - gas injectors with gas plate

Source: Author's archive

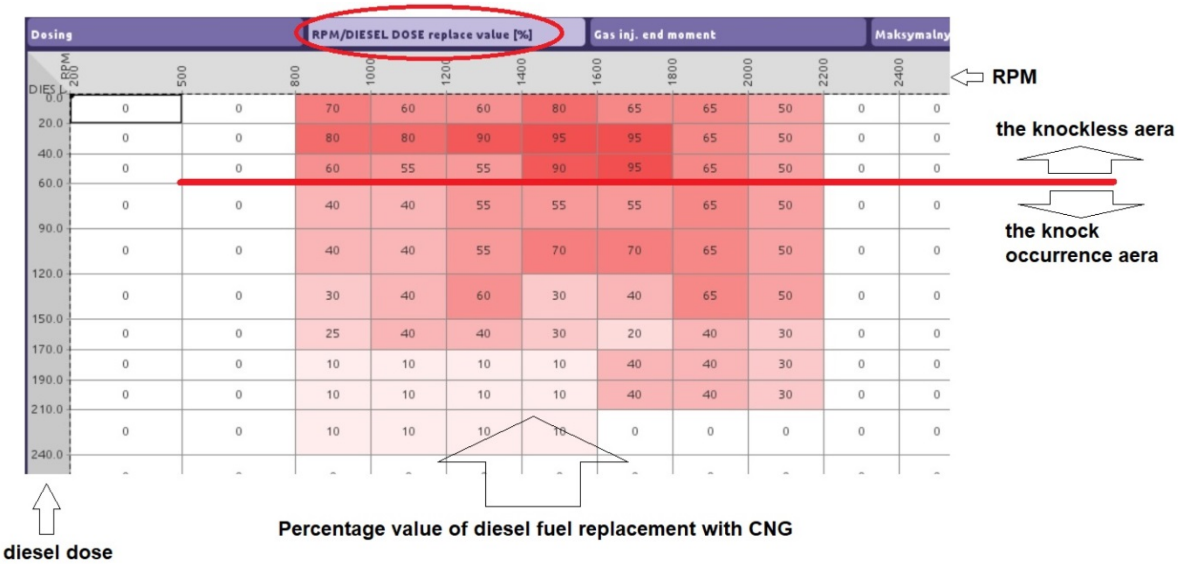


Figure 5 Screenshot from the gas controller software

Source: Author's archive

As the boost pressure increase, the percentage of fuel replacement decreases due to the appearance of knocking combustion. Injected Diesel fuel dose corresponds to the possibility of generating upper torque values by the tested engine. Figure 5 indicate a pressure reduction in the area of fuel exchange near the maximum possible to generate torque. During this test, pressure reduction was not implemented. There is a clear discrepancy in the applicability of high fuel replacement rates. This situation is most probably caused by the fact that by indirectly introducing gas fuel into the intake system of the engine, it fills the space that was originally distorted in the Diesel engine for air load and cause higher air mass charge. Thereby the engine becomes overloaded with the gas-air mixture, which ultimately causes the resulting end gas knocking combustion.

A pressure reduction in turbocharged engines can be realized in two ways:

1) using turbocharger air bypass valve circuit,
2) using turbocharger airflow modification:
   a) changing spring in wastegate actuator,
   b) installing two port boost control solenoid,
   c) installing three port boost control solenoid,
   d) installing two three port boost control solenoid.

All mentioned solution have one common purpose – to decrease boost pressure in intake manifold.

1.1. Air bypass valve circuit

Installing an air bypass valve in CNG-Diesel converted engines is common solution when decreased pressure is needed. A bypass with throttle is installed between intercooler and intake manifold. When pressure is higher than required in certain point of operation, turbocharged air bypass valve is tilting. This reduce air pressure and in fact amount of air introduced into combustion chamber when valves are opened and air mass charge is lowered. Pressure is decreased when controller tilt a throttle and air is released into inlet pipe, mostly into compressor inlet by T-connector (fig. 6).

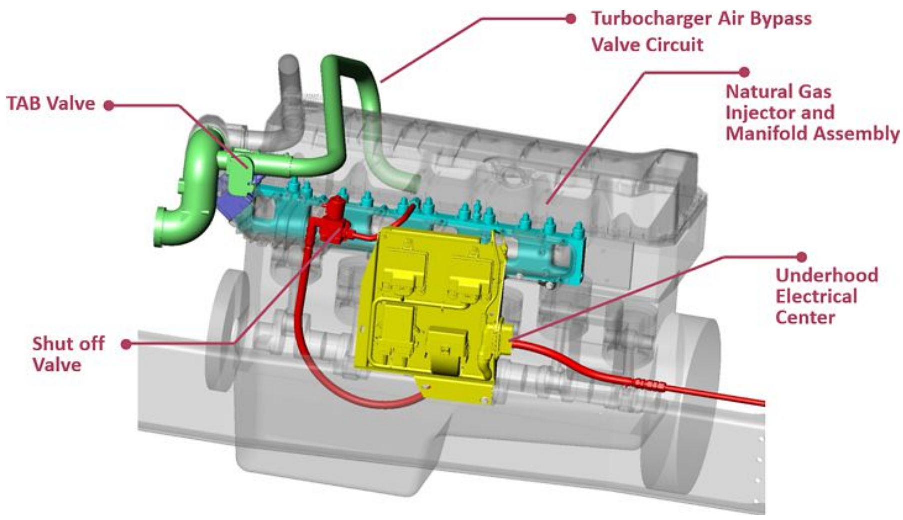


Figure 6 Air bypass valve circuit engine – Turbocharged Air Bypass valve

Source: [9]

This solution is known from engines like Volvo D13C460. Disadvantages of such solution is that require more changes in inlet system when such solution is not installed as an original installation but as an additional system. On the figure 7 we can see an example of Volvo engine with installed dual-fuel natural gas installation, where some mechanical changes in inlet system has to be done such as:

a) installing air bypass valve,
b) installing T-connector in original air inlet before turbocharger,
c) installing T-connector on original intake manifold.

Because of lack of space, inlet manifold has to be cut and welded to fix T-connector in appropriate place. Similar operation has to be done from air inlet before turbocharger side. A throttle must be operated from gas ECU, with respect to engine parameters such as air pressure and temperature in manifold, speed of engine, fuel replacement ratio, etc.

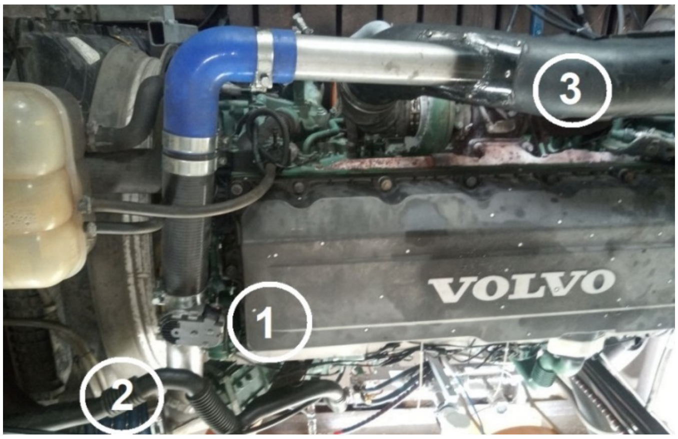


Figure 7 An example of air bypass installed as a retrofit system: 1 - air bypass valve, 2 – welded T-connector on manifold, 3 – air inlet T-connector before turbocharger

Source: Author's archive

1.2. Turbocharger airflow modification

This kind of solution interfere turbocharger efficiency which is controlled by wastegate and wastegate actuator or in advanced solutions, by turbocharger variable geometry. Such solution do not need mechanical changes in air duct but only on turbocharger pressure control system.

1.1.1. Spring in wastegate actuator

The simplest solution that enable to control turbocharger efficiency is to control air pressure by installing dedicated spring inside the wastegate actuator of dedicated boost pressure force (fig. 8). When pressure arise up to the spring value, wastegate is opening and exhaust gas pressure is relief. This cause decreasing of turbocharger efficiency.

Figure 8 Different spring tension for wastegate actuator

Source: [10]

Such solution is quite cheap and require minimum inference into original engine air inlet system. Unfortunately this is almost only one advantage of such solution. If the engine will be powered by Diesel fuel only, this pressure will reach only predefined value from spring tension. Important to notice is fact that changing a spring stiffness is required also in solutions where more advanced systems with solenoid for boost control is used.

1.1.2. Two ports boost solenoid

Two port boost control solenoid affect pressure that coming to wastegate actuator. Pressure that is present in compressor cover, before reaching wastegate actuator port, goes through T-connector (fig. 9). A tee connection is connected to solenoid, which can decrease pressure if needed by releasing pressure in duct pipe.

Solenoid must be operated by external controller. In converted engines, this solenoid is operated by ECU from CNG installation, similarly to air bypass. Similar parameters must be measured to ensure proper boost.

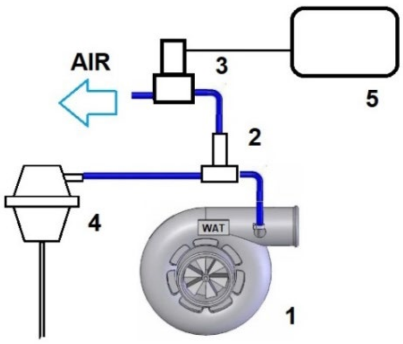


Figure 9 Two port boost control solenoid: 1 – turbocharger, 2 – ECU, 3 – solenoid,4 – wastegate actuator, 5 – tee

Source: Author's archive

If pressure is at required level, solenoid remains closed. This is when engine is operated in dual fuel mode. When required boost pressure must be higher, pulse width modulation (PWM) controlled solenoid is starts to opening and pressure coming to wastegate actuator is decreased. The longer solenoid is energized, the higher pressure will occur in manifold, because wastegate actuator spring can't open wastegate. This kind of operation lead to wastegate actuator remain close when it normally will be tilted and boost will be higher. A clean air from actuator is released into atmosphere or directly to the inlet duct. For this solution, if normal operation of the engine will be in dual-fuel mode, required boost is lover than normal boost and except solenoid, a spring inside wastegate actuator has to be changed to allow wastegate open with smaller pressure. Gas ECU can operate the valve with respect to different measured parameters, such as manifold absolute pressure sensor (MAP sensor), throttle position (in SI engines), air temperature, etc. This solution is quite advanced and if spring will be changed properly, even if solenoid will be broken boost pressure will not arise and the knock on dual fuel operation will not occur. The problem can be when solenoid will be broken and engine works in Diesel mode. This can cause to smoke occur, because of insufficient amount of air coming into engine.

1.1.3. Three ports boost solenoid

A three port solenoid is more advanced solution than two ports solenoid. Directly connected to the pressure duct pipe (fig. 10) can interrupt pressure that is going to the wastegate actuator. Additional port in solenoid enable to vent air to the atmosphere or to the air inlet. In normal condition, solenoid is open and pressure from compressor cover feed up a wastegate actuator without the same pressure level. When solenoid is energized with PWM signal, by additional port pressure from duct pipe, air pressure is decreasing and pressure that can open actuator is lowered. Additional correction parameters can be taking into account, such as mentioned in chapter 1.1.2.

In this solution, due to delivering lowered pressure directly into wastegate, quicker spool, more accurate and more responsive system can be achieved than in two ports solenoid. A three point solenoid connected with adjusted spring parameters provide a possibility to generate pressure at required level.

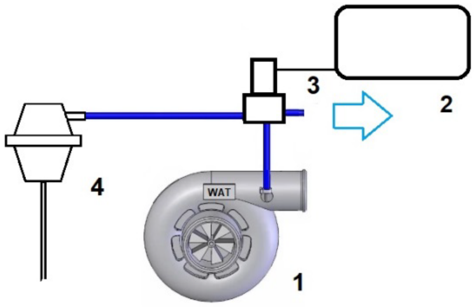


Figure 10 Three port boost control solenoid: 1 – turbocharger, 2 – ECU, 3 – solenoid, 4 – wastegate actuator

Source: Author's archive

1.1.4. Two three ports boost solenoid

Use a two three ports solenoid is most advanced solution among presented. It require a fast and advanced ECU because a two solenoids must be regulated simultaneously with respect of external engine parameters (fig. 11). For this solution, more elements must be added (solenoid) and wastegate actuator must enable to connect top and bottom air ports. This complex system offers a very broad possibilities for boost control, but require a complex parameters setup for proper work. In a fact this solution for engines that works in narrow and slow sped or load conditions can be too complex and if inappropriately tuned, can't offer system advantages.

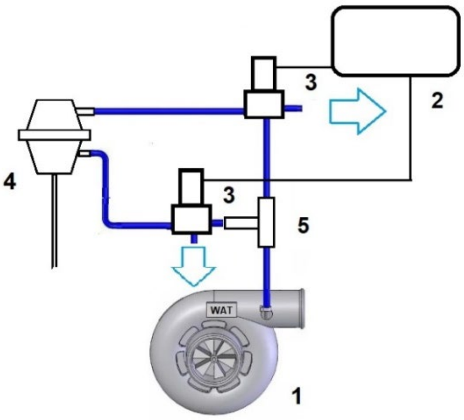


Figure 11 A two three port boost control solenoid: 1 – turbocharger, 2 – ECU, 3 – solenoid, 4 – wastegate actuator with top and bottom pressure control ports

Source: Author's archive

1.1.5. Other solutions

Except overmentioned, different solutions of controlling a boost pressure can be met. They were not described widely because of insufficient control possibility such as manual boost controller, where boost level is set manually and when environmental parameters changes (temperature or pressure), setting has to be readjusted. A four-way solenoid, that controls actuator top and bottom can, is much advanced but his work can be unstable and cause pressure fluctuation.

Some engines are using variable geometry of turbocharger and this might help to achieve required lowered boost, but this is not a standard and will required one of overmentioned solutions.

A solution which was not investigated yet and can offer wide range of setups is electronic wastegate actuator (fig. 12). This solution will be a subject of further work and analysis.

Figure 12 Electronic wastegate actuator

Source: [11]

3. CONCLUSIONS

CNG has great potential for use in a dual-fuel engine system. It is possible to set up engine with parameter similar to Diesel powered only but meet more restrictive standards.

A big problem, when introducing natural gas, is possibility to knock occur. The literature deals with knocking problems in a diesel-CNG dual-fuel engines. Empirical studies also confirmed the problem of dual-fuel knocking, in particular when trying to obtain high values of torque and with high load. High torque is created close to the knock region and that is so important to avoid the knock but be close to it.

With increased boost pressure in turbocharged dual fuel engines, the percentage of fuel replacement decreases due to the appearance of knocking combustion. Indirectly introduced gas fuel into the intake system fills the space that was originally distorted in the diesel engine for air load. Engine becomes overloaded with the gas-air mixture, which ultimately causes the resulting end gas knocking combustion. This require introduce a system that will reduce boost accordingly to the engine load and fuel replacement.

Among many parameters that can cause a knock, in presented paper three were mentioned: fuel replacement ratio, gas injection advance, boost pressure. Those parameters can be adjusted in dual fuel engines without big engine conversion.

A systems that enable boost reduction were described in the paper: by installing air bypass valve or by changing point where wastegate is opening and as result lower boost is introduced into intake manifold.

A bypass valve require modification of air inlet system such as adding air throttle and connect intake manifold with air inlet duct before turbocharger. ECU of converted engine is responsible for providing required air pressure. This solution is well known and used by automotive companies.

Second solution, with his origins in motorsport, is to use a boost control setup that will also provide required air pressure, but less mechanical interferences are made. Accordingly to final solution, only turbocharger wastegate actuator is subjected to modification and one or two solenoids, operated by ECU, are added, without changes in manifold or other inlet elements.

REFERENCES

[1] https://www.euractiv.com/section/energy-environment/news/meps-back-natural-gas-as-a-bridge-to-100-renewable-hydrogen/

[2] https://www.railjournal.com/locomotives/russian-gas-turbine-locomotive-hauls-9000-tonne-train/

[3] https://logistyka.rp.pl/transport/4267-czy-gazowce-truja-bardziej-od-diesli - acces: 20.06.2021 r.

[4] https://nijhof-wassink.com.pl/czyste-i-tanie-paliwo/ - access: 20.06.2021 r.

[5] Heywood, J. B.; Internal Combustion Engine Fundamentals, Second Edition, McGraw-Hill Education, USA 2018, 519-597;

[6] Karim, G. A.; Fuel Energy and the Environment, CRC Press, Boca Raton, FL, USA 2012

[7] Karim, G. A.; Dual-fuel diesel engines, CRC Press, New York, USA 2015

[8] https://gazeo.com/automotive/technology/Bosch-Dual-Fuel-future-of-diesel-engines,article,7831.html

[9] K. Kuiken, Gas and dual-fuel engines. Dania 2017 r. https://dieselnet.com/tech/engine_natural-gas_heavy-duty.php

[10] www.falconturbos.com

[11] https://www.tuningblog.eu/pl/kategorien/tipps_tuev-dekra-u-co/elektronisches-wastegate-252316/

THE CONTROL SYSTEM FOR A SWARM OF AUTONOMOUS UNDERWATER VEHICLES – PRELIMINARY RESULTS

Tomasz Praczyk
Polish Naval Academy, Department of Computer Science
Gdynia, Poland
E-mail: t.praczyk@amw.gdynia.pl

Leszek Pietrukaniec
Polish Naval Academy, Department of Naval Weapon
Gdynia, Poland
E-mail: l.pietrukaniec@amw.gdynia.pl

UDK 629.56(204.1)
551.465.5

Summary

Autonomous underwater vehicles are a valuable alternative for manned systems meant for searching for ferromagnetic objects buried in the sea bottom. The currently used solutions which are based on the system of magnetometers towed by a ship are very expensive in use. The same task can be performed by a swarm of vehicles-magnetometers moving near the sea bottom in a tight formation. However, in order for the vehicles to be able to replace the traditional solutions, the swarm formation must be kept with a high accuracy. To this end, a very accurate vehicle control system is necessary. In the paper, a solution is proposed which controls a single vehicle along a desired trajectory in the presence of the sea current with the time synchronization. In addition to the control system itself, the first tests on the system are also reported in the paper.

Keywords: Autonomous underwater vehicles, Control, Swarm, Ferromagnetic objects detection

1. INTRODUCTION

Offshore wind farms are increasingly popular source of green energy around the world. However, in order for the farm to arise, first, its future localization has to be carefully examined in terms of the presence of dangerous objects, e.g. ferromagnetic objects buried in the sea bottom. To this end, magnetic anomaly detectors (MAD) are applied which are composed of a set of magnetometers. The combined signal of all the magnetometers towed by a ship near the sea bottom is a base for detecting anomalies in the Earth magnetic field produced by ferromagnetic objects.

Since the MAD system described above is a towing system that requires a towing ship, its application at sea is a very expensive undertaking. In order to cut down costs of the detecting process, a swarm of autonomous underwater vehicles (AUV) can be applied instead. However, in order for the vehicles to be able to replace the traditional solutions, the swarm formation must be kept with a high accuracy.

In general, there are at least two different solutions which can be applied for that purpose. The first one is to use one leader vehicle equipped with an accurate navigation system (NS) and a group of swarm members with the role to follow the leader [1,3,4,7,8,11,12,14,15]. To do so, the swarm members have to be in the possession of the information about their distance and bearing to the leader. To acquire this information, acoustic communications systems, active sonars, and optical devices can be applied.

The second swarm solution, which the current paper is focused on, is to apply vehicles moving independently along their own trajectories, which however, are close to each other [6,10]. Moreover, the necessary condition to obtain a tight vehicle formation is also synchronization in time of all swarm members. To accomplish such effect, a very accurate vehicle control system (CS) and navigation system (NS) are necessary. The task of the CS is to control each swarm member along a desired trajectory with the time synchronization whereas the task of the NS is to constantly supply the CS with the information about position of the vehicle, its speed and heading.

In addition to the two approaches mentioned above, there are also other robotic swarm solutions, which however are not suited to the problem of detecting anomalies by a tight team of underwater vehicles. In [13], the system is proposed that is meant for exploration task. To control the vehicles, two bioinspired algorithms are applied, i.e. bee and slime mould algorithms.

In [2], a distributed swarm control approach is given. It does not assume any leader vehicle, however, the swarm members coordinate their behavior without previously arranged plan of mission. They work in a synchronized manner by exchanging messages between themselves that coordinate joint work.

Leader-follower model is also presented in [15]. However, it does not assumes fixed formation of the swarm. In this approach, the vehicles can switch over to different formation topologies. Moreover, they are also subject to switching topologies, periodic disconnection, hybrid localization, and system constraints.

In the paper, the CS system is proposed whose the main challenge is to keep the vehicle inside a desired trajectory with the time synchronization in the presence of an unstable sea current of a different strength. The CS works on a horizontal (XY) plane - the depth control is the responsibility of another system.

In order to verify effectiveness of the proposed system, the tests in simulation conditions were carried out. The system itself, the simulation model of an underwater vehicle, and the water environment were implemented in CUDA C++ (parallel GPU computing). The above implementation enabled intense training (optimization) and testing of the system for different strength of the sea current and different types of vehicles. The paper reports all the tests.

The contribution of the paper is threefold:

- the CS is proposed whose task is to lead an underwater vehicle along a predefined path with the time synchronization in the presence of an unstable sea current of a different strength;
- the proposed CS is optimized with the use of Differential Evolution algorithm;
- the proposed CS is qualitatively evaluated in simulation conditions for different types of vehicles.

The rest of the paper is organized as follows: section two presents the CS, section three reports simulation experiments, and the final section is the summary.

2. CONTROL SYSTEM

2.1. Preliminaries

The operation of the system is based on the assumption that the swarm consists of three vehicles moving in a very tight parallel-line formation, i.e. with the distances between the neighbours that amount up to 1.5-2 meters. The consequence of this is a very similar influence of environmental disturbances on each swarm member. In other words, it is assumed that the sea current which pushes the vehicles from the track is practically the same for each vehicle. This, in turn, means that if the vehicles get off the track they do this in the same direction which implies a very low probability of the collision between vehicles caused by the sea current.

The NS and errors generated by this system are a next cause of possible collisions inside the swarm. However, the application of a very accurate NS based on LBL and supported by the dead reckoning equipped with DVL and optical gyro should maximally decrease NS errors and thus reduce the likelihood of the collision to minimum.

In addition to the environmental disturbances and errors of NS, obstacles on the swarm track and the collision avoidance procedure applied in each vehicle are a next potential cause of in-swarm collision. To overcome this problem, the assumption is made that all obstacles are avoided by changing depth. The horizontal path of each vehicle is not violated in this case. What is more, the vehicles avoid collisions independently of other swarm members.

All the assumptions to the system specified above, mainly regarding the influence of the environment and a high accuracy of the NS, mean that in order to obtain a swarm of vehicles moving close to each other along parallel paths, there is no need to implement any system aiming at coordinating vehicles inside the swarm. The vehicles can operate independently without any in-swarm communication and the only need is to provide the system with the ability to keep a path assigned to each vehicle individually.

Given that each vehicle path is determined by a set of way-points and each segment between two way-points has a march velocity assigned, it is possible to determine, at each point in time, a desirable position of the vehicle and two errors of the position, i.e. the position error calculated along the path - EA, and the position error perpendicular to the path - EP. EA error indicates the timing error, that is, being late or ahead of time whereas EP error corresponds to the distance to the right path.

The CS presented in the further section assumes that the vehicles are modelled by means the algorithm implemented in MOOS-IvP [17] application called uSimMarine. In the algorithm, the vehicles are characterized by the following parameters: : S_{max} – maximum speed, T_{max} – maximum thrust, R_{max} – maximum position of the vehicle rudder, $ThrustMap$ – a data structure used to simulate a non-linear relationship between thrust and speed, $TurnLoss$ – the parameter in the range [0,1] which determines loss of speed while the vehicle turn, when set to zero, there is no speed lost in any turn, when set to one, there is a 100% speed loss when there is a maximum rudder, $TurnRate$ – the parameter in the range [0,100], the value zero means no vehicle turn regardless of the vehicle rudder setting, $MaxAcceleration$ – the maximum vehicle acceleration, $MaxDecceleration$ – the maximum vehicle deceleration, $RotateSpeed$ – the external rotational speed that influences the change of vehicle heading, $MaxRudderV$ – the maximum rotational speed of the rudder in degrees per second.

2.2. Control algorithm

The task of the CS proposed in the paper is to minimize EA and EP. To this end, the CS controls both heading and speed of the vehicle. The heading of the vehicle HDG is calculated as follows:

$$HDG = H((x, y), (xg, yg)) \tag{1}$$

where $H(a, b)$ is the heading from point a to point b, (x, y) is the current position of the vehicle, whereas (xg, yg) is a local destination point for the vehicle which is calculated as follows:

$$(xg, yg) = P((xp, yp), A, D) \tag{2}$$

where $P(c, e, f)$ is a function which generates a point located in the distance f from point c in the direction e, whereas (xp, yp) is a point lying at the intersection of two straight lines, i.e. the straight line between the previously visited way-point (xwp, ywp) and the next way-point (xwn, ywn) and the perpendicular straight line passing through the point (x, y).

The direction A and the distance D are calculated as follows:

$$A = H((xwp, ywp), (xwc, ywc)) \tag{3}$$

$$D = \begin{cases} \alpha p_1 \text{ if } d\big((xp, yp), (xwn, ywn)\big) > \alpha p_1 \\ \qquad d((xp, yp), (xwn, ywn)) \end{cases} \tag{4}$$

where d is the distance between two points in space, $p_1 \geq 0$ is the parameter of the method, and α is defined as follows:

$$\alpha = \begin{cases} \frac{1}{1+p_2 EP} & \text{if } EP > p_3 TurnRate \\ 1 & \text{otherwise} \end{cases} \tag{5}$$

where $p_2 \geq 0$ and $p_3 \geq 0$ are next CS parameters and $TurnRate$ is a vehicle parameter.

According to the above algorithm, the vehicle heading depends on EP, three CS parameters, i.e. p_1, p_2, p_3 and the vehicle parameter which determines manoeuvrability of the vehicle. EA and does not affect the heading.

In turn, the speed S of the vehicle is calculated according to the following procedure:

$$S = \max(0, \min(S_{max}, S_n^m + 0.5(S_1 + S_2))) \tag{6}$$

where S_n^m is the march speed while moving to the next way-point whereas, S_1, S_2 are defined as follows:

$$S_1 = \begin{cases} EA' p_4 & \text{if } EA > p_5 V \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

$$S_2 = \begin{cases} EP p_6 & \text{if } EP > p_7 V \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

where $EA' = \begin{cases} EA & \text{if the vehicle is being late} \\ -EA & \text{otherwise} \end{cases}$, $p_4 \geq 0, p_5 \geq 0, p_6 \geq 0, p_7 \geq 0$ are CS parameters, and V is defined as follows:

$$V = p_8 ThurnLoss + p_9 MaxAcceleration + p_{10} MaxDecceleration \tag{9}$$

where p_8, p_9, p_{10} are the last CS parameters.

Unlike the vehicle heading, the speed S depends on both EA and EP and on vehicle parameters condensed in V. For small values of both errors, the speed S is equal to the march speed. If EA or EP exceed a threshold, the march speed is accordingly modified. S_1 is an extra vehicle speed which is added to the march speed if EA exceeds the threshold $p_5 V$, whereas S_2 is an extra speed that is also added to the march speed if EP exceeds the threshold $p_7 V$. S_1 can be positive as well as negative, whereas S_2 is always positive. S_1 is positive if the vehicle is late and negative if the vehicle is ahead of time. The algorithm has seven parameters, i.e. $p_4, \dots, p_{10}$.

In order to control the vehicle, its speed and heading have to be appropriately converted into thrust T and position of rudder R. To this end, the following simple speed and heading controllers are applied:

$$T = \begin{cases} S p_{11} & \text{if } |S| > S_t \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

$$R = p_{12} to180deg(HDG - HDGC) \tag{11}$$

where S_t is a speed threshold for activating thrust, p_{11}, p_{12} are controller's parameters, and $to180deg$ is a function which converts an angle to the range $< 0, \pm 180 >$deg.

The CS has a very simple construction, however, its effectiveness is strongly dependent on parameters $p_1, \dots, p_{12}$ which have to be optimized before controller application.

3. EXPERIMENTS

3.1. Conditions of the experiments

In order to verify effectiveness of the proposed CS, experiments in simulation conditions were carried out. The experiments took place in two phases. The task of the first phase was to optimize the CS, that is, to find, optimal values for parameters $p_1, \dots, p_{12}$. In this phase, the task of the CS was to control two different vehicles, say, vehicle one (V1) and vehicle two (V2). In turn, the task of the second phase was to verify effectiveness of the optimized CS (with fixed values of $p_1, \dots, p_{12}$) on three further vehicles, say, vehicle three, four and five (V3, V4, V5), All the five vehicles differed in the parameters $TurnLoss$, $TurnRate$, $MaxAcceleration$, and $MaxDecceleration$ – see Table 1.

The remaining parameters of the vehicles were as follows: : $S_{max} = 2$ m/s, $T_{max} = 100$, $R_{max} = 100$, $ThrustMap = 0{:}0{,}20{:}1{,}40{:}2$, $RotateSpeed = 0$, $MaxRudderV = 40$. The difference in behaviour of all the vehicles is depicted in Figure 1 and 2. The figures show how fast the vehicles reach a desirable values of speed and heading. The behaviour shown in the figures was recorded for some fixed parameters of thrust and rudder controllers.

Table 1 Parameter of vehicles

	$TurnLoss$	$TurnRate$	$MaxAcceleration$	$MaxDecceleration$
V1	0.85	70	0.5	0.5
V2	0.75	20	0.5	0.5
V3	0.55	50	0.7	0.7
V4	0.95	90	0.3	0.3
V5	0.65	30	0.7	0.3

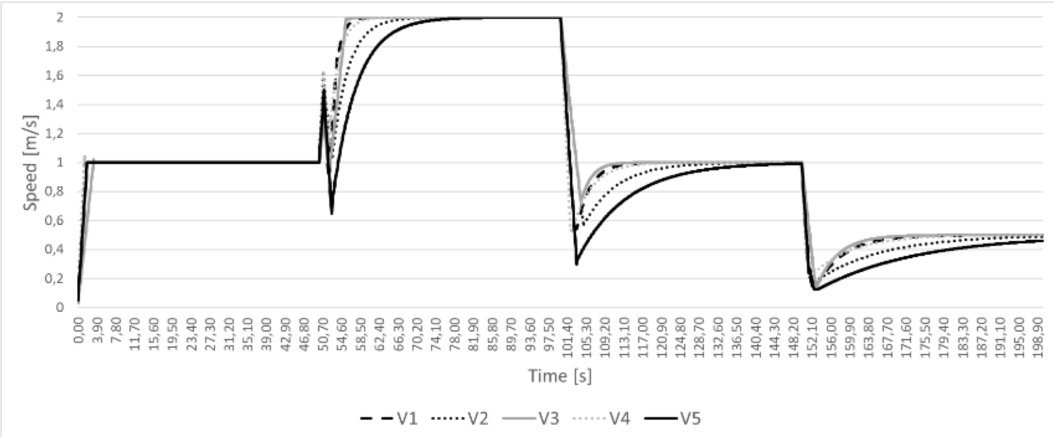


Figure 1 The change of speed

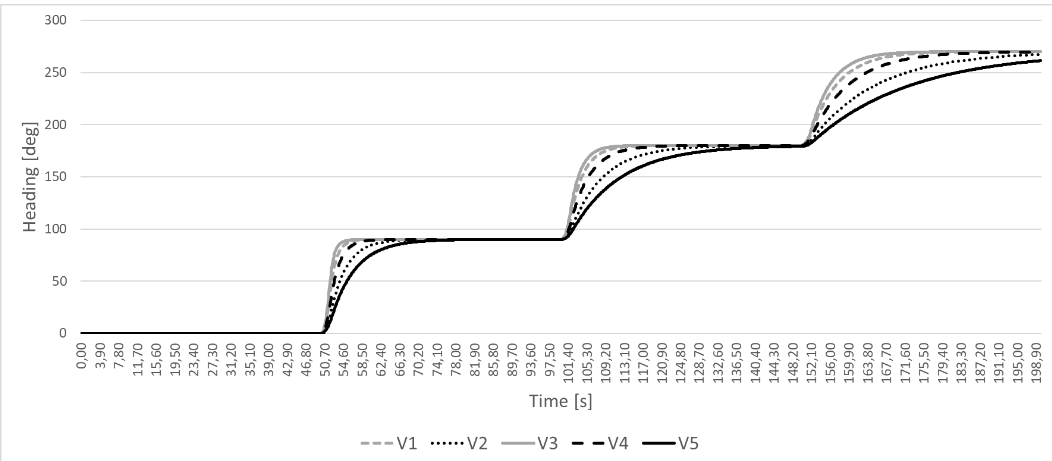


Figure 2 The change of heading

Other parameters of simulations were as follows: $S_t = 0.001$ m/s, $\Delta t = 0.1$ s ($\Delta t -$ simulation step).

The task of the vehicles was to follow a lawn-mower trajectory consisting of eight way-points and seven straight segments, i.e. three 100 meter long scanning-bottom segments and four turning-back segments. The coordinates of way-points, their order, heading of the vehicle along the scanning-bottom segments as well as the march speed MS assigned to each segment, are as follows: $(20{,}20) \rightarrow 90°, 1\frac{m}{s} \rightarrow (120{,}20) \rightarrow 0.5\frac{m}{s} \rightarrow (140{,}22.5) \rightarrow 0.5\frac{m}{s} \rightarrow (120{,}22.5) \rightarrow 0°, 1\frac{m}{s} \rightarrow (20{,}22.5) \rightarrow 0.5\frac{m}{s} \rightarrow (0{,}25) \rightarrow 0.5\frac{m}{s} \rightarrow (20{,}25) \rightarrow 90°, 1\frac{m}{s} \rightarrow (120{,}25)$. The march speed assigned to each turning-back segment was reduced intentionally so as to provide the vehicle enough time for turning-back manoeuvre.

For the conditions of the experiments to be maximally similar to the real ones, the vehicles were subject to the sea current which had random duration, direction and strength. It appeared regularly every 6s at most, and its maximum duration amounted to 2s. The direction of the current amounted to $45° \pm 10°$, whereas its strength amounted maximally to 0.8 m/s or 0.4 m/s.

In order to optimize the CS, Differential Evolution (DE) [5,9] algorithm was applied. Each CS produced by the DE was run forty times along the trajectory specified above, twenty times for vehicle V1 and twenty times for vehicle V2. Each run differed in the sea current and it could be interrupted if EA or EP exceeded a threshold. To evaluate all the forty runs the following fitness function was used:

$$F\big(CS(\boldsymbol{P})\big) = NW + \frac{1}{1+EA_{max}+5EP_{max}} \quad (12)$$

where $\boldsymbol{P}$ is a vector of CS parameters, NW is the number of way-points which the vehicle reached in all the forty runs, whereas EA_{max} and EP_{max} are the maximum errors of CS during the evaluation process. The evaluation of each CS took place only along scanning-bottom segments of the trajectory.

The DE was run thirty times in total. The most effective CS's in each DE run were put to the extra generalization test which consisted of further forty attempts to cover the testing trajectory. In this case, the CSs controlled vehicles V3, V4, and V5. Each attempt took place in conditions which CS's had not experienced before. To evaluate the generalization performance of CS's, function (12) was applied again.

3.2. Experimental results

Two the most effective CS's in the generalization phase were chosen after all the experiments, one for the current 0.8 m/s and another one for the current 0.4 m/s. The parameters of both CS's are as follows: for current 0.8 m/s – P1=2.02475, P2=4.14569, P3=0.963423, P4=5.41067, P5=0.279992, P6=6.64317, P7=0.793947, P8=0.048867, P9=-0.380790, P10=0.975703, P11=19.090159, P12=1.814808, for current 0.4 m/s – P1=2.60580, P2=9.89495, P3=0.756911, P4=5.83256, P5=0.308118, P6=1.44903, P7=1.016164, P8=0.550444, P9=0.565465, P10=-0.602191, P11=19.512038, P12=1.775458. The results of both CS's are summarized in Table 2. Moreover, example errors and vehicle trajectories are presented in Figures 3-6.

Table 2 The results of both selected CS's

	fitness	Max EA[m]	Max EP[m]	Mean EA[m]	Mean EP[m]
0.8 m/s	360.159	1.29	0.79	0.17	0.13
0.4 m/s	360.247	0.56	0.49	0.09	0.08

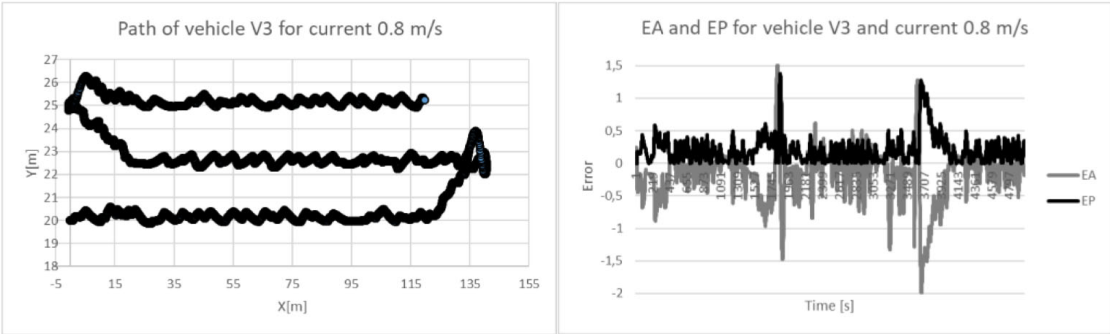


Figure 3 Example path and errors EA, EP for vehicle V3 and for the maximum current strength equal to 0.8 m/s (the greatest errors occur in turning-back segments that were not evaluated, negative values of EA mean that vehicle is ahead of time)

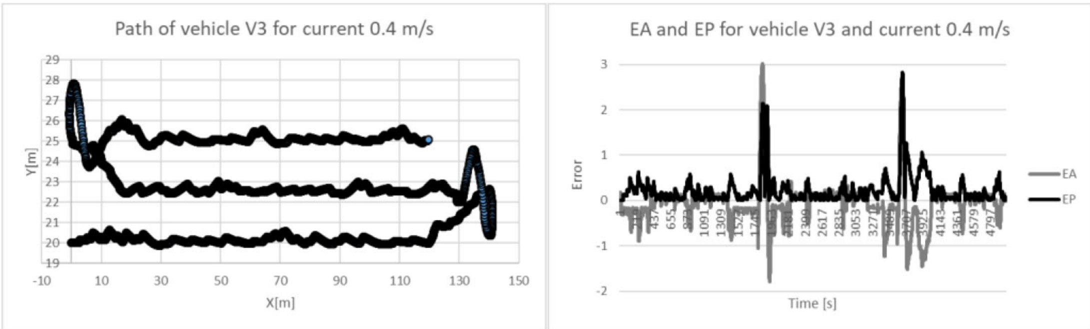


Figure 4 Example path and errors EA, EP for vehicle V3 and for the maximum current strength equal to 0.4 m/s (the greatest errors occur in turning-back segments that were not evaluated, negative values of EA mean that vehicle is ahead of time)

The results given in Table 2, especially mean errors, are encouraging and show that it is possible to accurately control the vehicle along the lawn-mower trajectory even with the use of very simple controller and in conditions of a very strong sea current. EA errors are generally greater than EP errors which results from the fitness function (12) applied in the optimization process, which is more focused on minimization of EP than EA. The objective of such fitness function construction was to minimize probability of collisions between neighbouring vehicles as much as possible.

The results presented above are only preliminary results. Further research will mainly concentrate on different trajectory control algorithms, including artificial neural networks.

An important issue in the future research will be adaptability of the CS to different vehicle designs. The research in simulation is always the first step in designing an effective controller, which finally has to be moved to the real vehicle and appropriately tuned. Adaptability of the controller is a key factor in this process. The lack of the adaptability or low adaptability may result in the necessity of optimizing the controller from scratch on the real vehicle which for a complex controller may be difficult or even impossible.

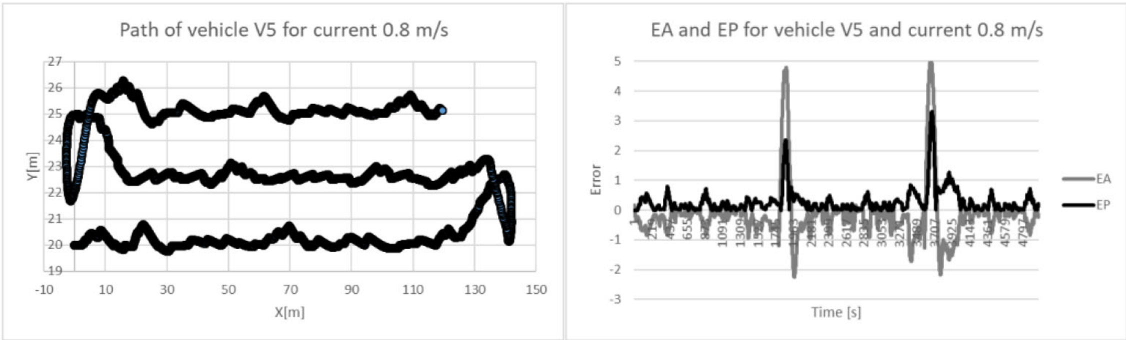


Figure 5 Example path and errors EA, EP for vehicle V5 and for the maximum current strength equal to 0.8 m/s (the greatest errors occur in turning-back segments that were not evaluated, negative values of EA mean that vehicle is ahead of time)

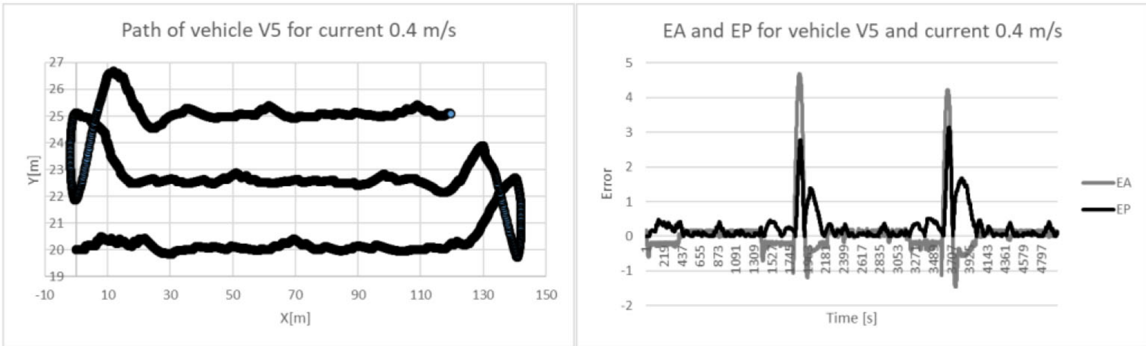


Figure 6 Example path and errors EA, EP for vehicle V5 and for the maximum current strength equal to 0.4 m/s (the greatest errors occur in turning-back segments that were not evaluated, negative values of EA mean that vehicle is ahead of time)

Currently, the CS operation depends only on four vehicle parameters, that is, on $TurnLoss$, $TurnRate$, $MaxAcceleration$, and $MaxDecceleration$, the remaining vehicle parameters considered in MOOS-IvP vehicle model are neglected in controller design. In consequence, the controller can be applied to control a limited set of vehicles. In order to extend this set, further research is necessary on a new controller which will be sensitized to all parameters.

The other issue is a depth control. In the experiments reported in the paper, the vehicles were moving in the horizontal plane, without change of depth. In a real environment, the vehicles will be also forced to change depth, for example, to avoid collisions with encountered obstacles. In order to prepare the controller to work in conditions maximally similar to the real ones, the future research will be conducted in XYZ world with obstacles that will require the change of depth.

3. SUMMARY

The paper shows the first steps in designing the Control System meant for underwater vehicles aiming at searching for ferromagnetic objects in the sea bottom and operating in a tight swarm formation. In addition to the specification of the proposed simple CS, the paper also reports preliminary research in simulation conditions. They revealed that it is possible to design an effective CS capable of controlling a simulated vehicle even in the conditions of the very strong sea current. The research will be continued with the use of different more advanced control algorithms, including artificial neural networks.

REFERENCES

[1] Bikramaditya D., Bidyadhar S. & Bibhuti Bhusan P.: Co-operative control of a team of autonomous underwater vehicles in an obstacle rich environment, Journal of Marine Engineering & Technology, 2016, 15:3, 135-151, DOI:10.1080/20464177.2016.1247636.

[2] Chao M., and Wei W.: Distributed synchronization of autonomous underwater vehicles with memorized protocol, International Journal of Advanced Robotic Systems, March-April 2019: 1–9

[3] Ciu R. et al.: Leader-follower formation control of underwater AUVS with leader position measurement, In Proceedings - IEEE International Conference on Robotics and Automation, 2009, pp.979-984.

[4] Ciu R. et al.: Leader-follower formation control of underactuated autonomous underwater vehicles, Ocean Engineering, 2010, 37(17-18), pp.1491-1502.

[5] Feoktistov, V.:Differential Evolution: In Search of Solutions, Springer, 2006, ISBN 978-0-387-36895-5.

[6] McColgan J.: Development of a Formation Control Algorithm to Coordinate Multiple Biomimetic AUVs in the presence of Realistic Environmental Constraints, PhD thesis, University of Glasgow, 2018.

[7] Milla´n P., Orihuela L., Jurado I., et al.: Formation control of autonomous underwater vehicles subject to communication delays. IEEE Trans Control Syst Technol 2014; 22(2): 770–777.

[8] Peng Z., Wang D., Wang H., et al.: Distributed coordinated tracking of multiple autonomous underwater vehicles. Nonlinear Dyn 2014; 78(2): 1261–1276.

[9] Price, K.; Storn, R.M.; Lampinen, J.A.:Differential Evolution: A Practical Approach to Global Optimization, Springer, 2005, ISBN 978-3-540-20950-8.

[10] Ramp S.R.: Preparing to predict: The Second Autonomous Ocean Sampling Network (AOSN-II) experiment in the Monterey Bay, Deep-Sea Research Part II: Topical Studies in Oceanography, 2009, 56(3-5), pp.68-86.

[11] Soares J. M., Aguiar A. P., Pascoal A. M., and Martinoli A.: Joint ASV/AUV Range-Based Formation Control: Theory and Experimental Results, 2013 IEEE International Conference on Robotics and Automation, 2013, pp. 5579-5585

[12] Toonsi, S.: Leader-Follower Approach with an On-board Localization Scheme for Underwater Swarm Applications, Master's thesis, King Abdullah University of Science and Technology, Thuwal, Kingdom of Saudi Arabia, 2019.

[13] Varughese J. C., Thenius R., Leitgeb P., Wotawa F., Schmickl T.: A Model for Bio-Inspired Underwater Swarm Robotic Exploration, IFAC-PapersOnLine, Volume 51, Issue 2, 2018, Pages 385-390

[14] Xiang X., Jouvencel B. and Parodi O.: Coordinated Formation Control of Multiple Autonomous Underwater Vehicles for Pipeline Inspection, International Journal of Advanced Robotic Systems, Vol. 7, No. 1 (2010), ISSN 1729-8806, pp. 075-084

[15] Xiang X., Jouvencel B., and Parodi O.: Coordinated formation control of multiple autonomous underwater vehicles for pipeline inspection. Int J Adv Robot Syst 2010; 7(1): 3.

[16] Zhang Y., Wang S., Heinrich M. K., Wang X., and Dorigo M.: Practical 3D formation control of an underwater robot swarm: Switching topologies, periodic disconnection, and hybrid localization, IRIDIA - Technical Report Series, Technical Report No.TR/IRIDIA/2020-006, May 2020

[17] https://oceanai.mit.edu/ivpman/pmwiki/pmwiki.php?n=IvPTools.USimMarine

PORT SHUNTING YARD SIMULATION MODEL

Rusca Aura
University Politehnica of Bucharest, Faculty of Transport
Bucharest, Romania
E-mail: aura.rusca@upb.ro

Rosca Eugen
University Politehnica of Bucharest, Faculty of Transport
Bucharest, Romania

Rusca Florin
University Politehnica of Bucharest, Faculty of Transport
Bucharest, Romania

Rosca Mircea

Perez-Acebo Heriberto

Olteanu Sergiu

UDK 656.212.5:656.615

Summary

The connection between maritime transport and rail network is made in port area using a port shunting yard. This rail station has activity dedicated to cargo flows from maritime terminals to land and opposite. The main roles of a port shunting yard in the case of the first type of flows are to receive wagons set from maritime terminals, to separate these wagons on land destinations, to compose trains and to keep these trains until the rail network dispatcher finds a free route in the rail traffic schedule. For the cargo flows from land these roles are to receive trains from port hinterland, to separate the wagons in corelation with their destination inside the port area, to accumulate the wagons until the terminals can receive these ones. To evaluate the transit capacity of a port shunting yard for both types of cargo flows a simulation model can be a useful tool. In our paper we propose a discrete simulation model developed using a dedicated software. The specific topology of port shunting yard is modelled using logical blocks, resources, simulation entities. The technological processes evaluated in our model are similar with real processes conducted in Romanian maritime shunting yards. The results obtained are useful in decisional process of port administration and for strategic plans of future development for new facilities in area of the port.

Keywords: port shunting yard, maritime terminal, railway network

1. INTRODUCTION

The logistic chains across the Earth have an important role in our society. The main production zones are connected to the final user of products by a large network on land, water, air. The main logistic chains have components from maritime transport and land transport. The connections between these components are made through maritime ports and special facilities located in their area. The big volume of cargo flows from maritime vessel to land network and opposite, the time and ecological restriction impose for maritime ports a good connection with rail network.

The cargo flows from maritime terminals to rail network and the opposite flows are conducted in most common cases through a shunting yard located inside the port or in their proximity. The roles of this rail station are to receive from land network, trains, to storage and to send the wagons for maritime terminals, to receive and to storage the wagons from maritime terminals, to send the wagons grouped as trains to their land destination.

The type of the shunting yard and the technology used are chosen in accordance with the specificity of the activity required in the railway station, the volume of cargo flows, the diversity of origin and destination of freight wagons. According to Steenken et al. for the case of maritime terminals can be identified three decision levels (terminal design, operative planning, real time control) [18]. The layout of the shunting yard is defined at first level based on a predicted cargo traffic. The adopted shape must allow an easy transit for flows from land and from maritime vessels. At second level is decided the allocation of tracks for input/output cargo flows in/from port area and are assigned tracks for storing the wagons up to the vessels arriving moment and for technical inspection of rolling stock. Finally, the daily activity is coordinated with first level decision adapted to real situation about trains and maritime vessels circulation, the structure of trains, the type of wagons used or other specific aspects for rail and maritime transport.

The quality and utility of these decisions must be proved by the specialists who proposed its using a mathematical model based on predicted or real data. When the quantity of information is big and decisional problems must be solved under conditions of uncertainty, the simulation model can be a useful tool in decisional process. To develop the simulation model the shunting yard can be modelled as a queuing system with a set of resources and with simulation entities generated after a mathematical distribution function. The model can be used for different input data patterns and can be tested with different technological process proposed for activity in the port shunting yard.

The results obtained show how the activity parameters as the number of wagons transiting to/from maritime terminals, the waiting time for a free resource, the utilisation rate of yard components vary in accordance with input data introduced in simulation model to test the scenarios proposed for shunting yard. The simulation model must be developed using an adaptable form for different transport terminals. The calibration and validation of the model ensure the validity of data obtained through simulation process.

2. LITERATURE REVIEW

The importance of shunting yards located in area of maritime ports for logistic chains leads to a series of research made by specialists in this domain. The dissemination papers can be separated in accordance with their subject in three categories:

- Maritime terminals: the connection between land network and maritime vessels is studied to evaluate the transit capacity, the influence of required conditions for dangerous goods, the capacity of storage area, the technological processes inside the terminal [10-12, 14, 17-18]. The applications are developed for the case of passenger's terminals [10-11], the case of cargo terminals transited by dangerous goods flows [12,14], container terminals [17-18]. The results obtained are useful in special in the terminal design level from decisional process.
- Shunting yard: the complexity of activity on rail network is found in a set of research. In these papers, the shunting yard has an important role to compose and decompose the cargo flows. For every type, the standard technology for shunting is presented. The decisional problem is solved to improve the activity inside the shunting yard. Strategic, tactical and operational tasks are developed concentrated on the hump yard. [1-5], [7-8]. A review for the typologies of shunting yard can be found in paper [5] with a good description for activities made inside the shunting yard. The technology used in separating the wagons according to their destinations and the methodology for using multiple shunting yards are described in paper [4, 7-8].
- Simulation model for transport terminals: the serving parameters for proposed scenarios can be evaluated using a simulation model. The transport terminal is considered as a queue system serving a set of simulation entities. In the case of applications made for maritime terminals these entities

represent maritime vessels, trucks, trains, containers [14-15, 17]. In the case of rail terminals is simulated the activity of trains and wagons inside shunting yards [6,9].

3. MAIN ASPECTS OF PORT SHUNTING YARD

On land, the shunting yard has the role to compose and to decompose the cargo wagons flows with different origin and destination points. The trains are received in the station on a dedicated area where a specialised staff makes the arrangements for train decomposing process. If in the station are accumulated enough wagons for a complete train, the train composing process is made using wagons with same destination or with destinations in the same direction. In case of yards located in port area some particularities appear in activity inside the rail station. The capacity of maritime vessels is 10-12 times bigger compared to trains. For example, if a Post Panamax container vessel can transport over 4000 TEU, a train on European rail network can transport only approximately 60-80 TEU. For this reason, the port shunting yard must reduce the transit time for wagons and must have available tracks to accumulate wagons from and to maritime terminals. The trains are received in maritime railway station and the wagons are separated on maritime terminal destinations in the end. The wagon sets accumulated are waiting in the station until the arriving moments of maritime vessels because the capacity of the terminal tracks is limited.

According to their layout and technology used to separate the wagons received in trains from land network or in wagon sets from maritime terminals the port shunting yards can be [5]:

- Gravity yard: It is the most simply yard. This is developed with a low declivity for an easy switching. The serving capacity is reduced and the duration of train's decomposing and composing processes is longer in comparison with the values obtained in other types of yards.
- Flat yard: Switch engines are used to separate the wagons. The yard has dedicated areas for receiving trains from land and for receiving wagon sets from maritime terminals, to accumulate wagons and for departing process made on trains with destinations located in port hinterland.
- Hump yard: It is the most complex yard. The transit capacity and serving parameters are improved through a special equipment dedicated to wagons separating process. This is like a hump with a specific height obtained through a complex calculation process and has a set of track brakes to retain the separating process of wagons in safety limits.

In case of shunting yards located in maritime ports with a large volume of cargo flow is recommended to be developed hump yards that can ensure the processing activity of the entire flow. The main areas of this type of railway station are (Figure 1):

- Receiving Tracks: this area is used for trains arriving from port hinterland and for wagon sets received from maritime terminals. The decomposing process is made to ensure the correct separation of wagons according with their destinations from land or from maritime port. For trains and wagon sets are made a technic inspection, a commercial inspection and other technological activities as decoupling the wagons and stopping the braking system.
- Classification Tracks: the wagons after the separating process are accumulated on these tracks until the departure moment to hinterland or to maritime terminals. The number of required tracks is obtained using data about the volume of cargo flows, the mean value of storage time for wagons in railway station, the specificity of activity inside the port area, the destination of wagons.
- Departure Tracks: is a dedicated area for trains composing process and also for waiting time until the moment when the train is accepted for departure on railway network. The circulation of trains is made according to a fixed timetable, the trains departure moments are decided according to this framework.

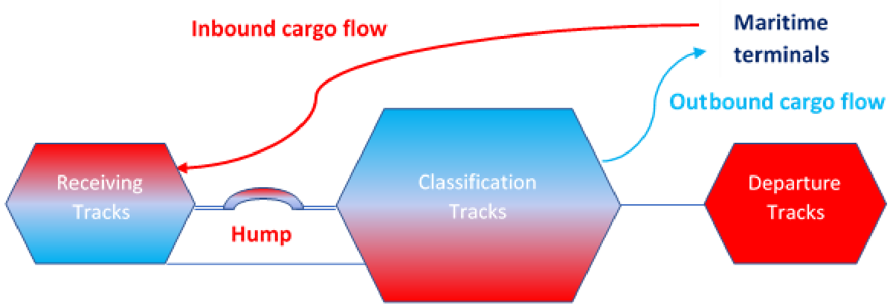


Figure 1 The main areas of port shunting yard (after [14])

Two methods can be used for yard transit capacity.First method is an analytical one, using mean value for the volume of cargo flows and duration of technological process. According with the activity flow inside the port shunting yard is important to calculate the value of transit capacity for Receiving Tracks area and also the transit capacity of the hump. First, the capacity can be measured in trains and is calculated with the following relation:

$$n_{trains} = n \frac{1440 - \sum T_{perm}^{RT}}{t_{receiving} + t_{process\_technologic} + t_{waiting}} \quad (1)$$

where

- 1440 represent the number of minutes from a day;
- $\sum T_{perm}^{RT}$ is the time interval when activity inside the Receiving Tracks area is stopped due to certain events (incompatible movements, engines going to depot, tracks maintenance);
- $t_{receiving}$ is the necessary time interval for receiving a train in the railway station;
- $t_{process\_technologic}$ is the necessary time interval for specific technological process made in Receiving Tracks Area (commercial inspection, technical inspection, other);
- $t_{waiting}$ represent the waiting time in the case when the hump is busy;
- n is the number of tracks in Receiving Tracks Area.

Secondly, the capacity can be measured in wagons and is calculated with the relation:

$$n_{wagons} = m \frac{1440 - \sum T_{perm}^{dt}}{t_d + t_{pres} + t_{int\ r}} \quad (2)$$

where

- 1440 represent the number of minutes from a day;
- $\sum T_{perm}^{dt}$ is the time interval when the hump is occupied with permanent operations (as shunting process for wagons coming from repair zone or from station storage area, engine reloading time, etc.);
- t_d represent the necessary time interval for a shunting process;
- t_{pres} is the time interval for a pressing process (removal of spaces between wagons with the help of an engine or a specific railway trolley) in Classification Tracks area;
- $t_{int\ r}$ represent the duration of interruptions of shunting process due to incompatible movements;
- m is the mean number of wagons from a train set.

The second method is taking in consideration the aleatory aspects of cargo flows. The activity inside the port yard is simulated considering the yard as a cascade queueing process. This method is close to reality and the developed simulation model can be used to evaluate a set of scenarios. The results obtained can be used in the decisional process and also help in reduction of uncertainty. The entities simulated are associated with trains from port hinterland, and wagon sets received from maritime terminals.

4. THE DISCRETE SIMULATION MODEL

The development of the simulation model must be made in accordance with the technological processes from maritime port shunting yard. The inbound trains from port hinterland and wagon sets received from maritime terminals are processed in Receiving Tracks area. The shunted wagons are accumulated in Classification Tracks Area and in Departure Tracks area are processed the outbound trains. The functional relations between the main departments of the rail stations must be part of the logical model used in the simulation. The structure of the simulation model is developed using Arena Rockwell Software and is depicted in Figure 2.

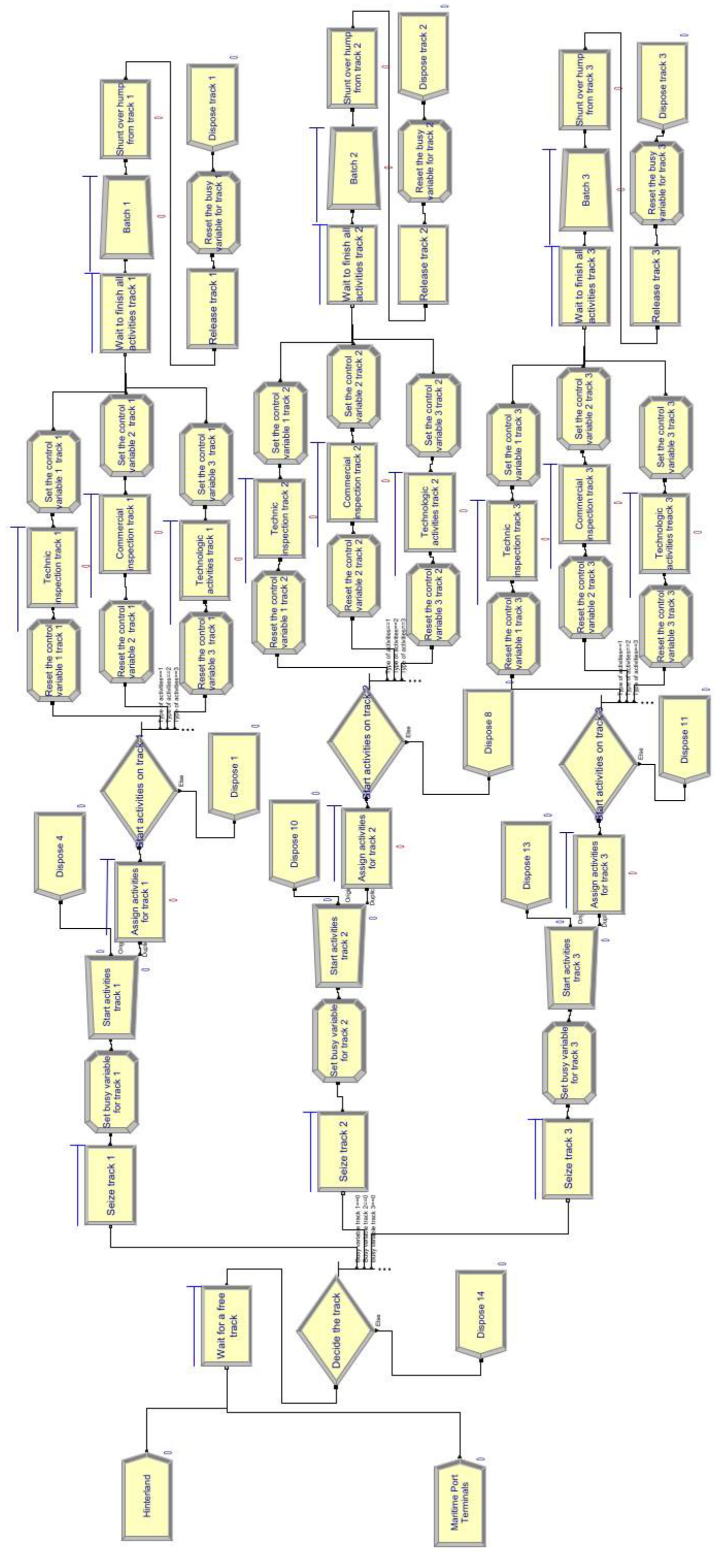


Figure 2 The discrete simulation model

The model contains two logical blocks for generating simulation entities corresponding for trains composed of wagons for maritime terminals and wagon sets from these ones with destination to hinterland locations or other maritime terminals. After generating the entities, Hold blocks are introduced to retain the entities until a free track in Receiving Area is free. A decisional block is used to decide the track that will be occupied for Receiving process (commercial inspection, technical inspection, other specific operations) made before shunting process (Figure 3).

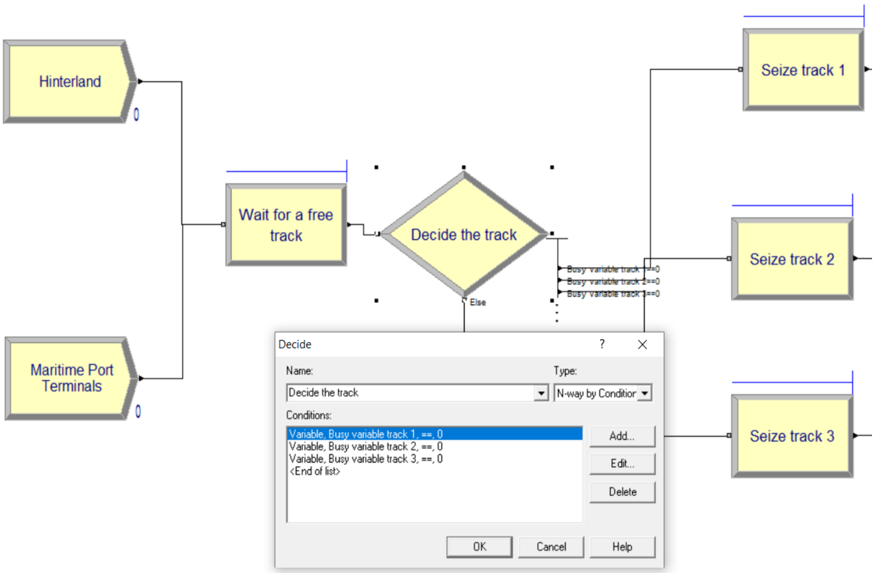


Figure 3 The allocation of a track in Receiving Area

The simulation path is divided for every track. In figure 4 is presented the process simulated for Track 1. When a simulation entity is allocated to a track this is seized. An occupancy variable is set to a predefined value (1 in our case) to avoid having two entities on the same simulation path in the same time. The next step is to divide the entity in multiple entities, one for every activity made in this area (technical inspection, commercial inspection, technological activities). The next step is made only when all activities are finished. For this control variables are initialized ant tested in a Hold simulation block. When the condition is met the entities obtained in the last dividing process are unified and the shunting process is started. To avoid double simultaneous shunting processes (because the hump is equipped with two tracks) the hump is set as a simulation resource. If this is used on another simulation path the shunting process is delayed and the entity wait for a free resource. Finally, when the process is finished the track is released and the value of the occupancy variable is changed again to another predefined value (0 in our case).

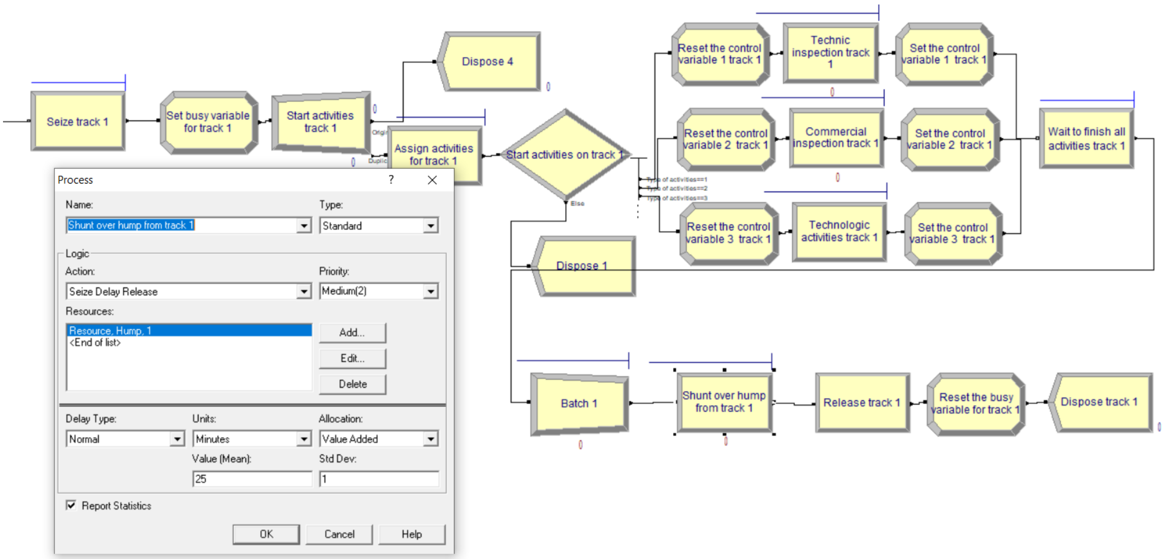


Figure 4 The simulation path for one track

5. SIMULATION SCENARIOS AND RESULTS

The simulation model is developed for a particular case with three available tracks and three simulation paths inside the model. If it is necessary, the number of simulation paths can be adapted for another number of tracks in Receiving Area. The number of tracks used to receive trains or wagon sets must be set in accordance with the specificity of the activity inside the railway station. For example, the shunting process is made using a manoeuvring engine. After a train is decomposed (shunted) the engine must be moved to another train using a free track.

A set of simulation scenarios (S1-S7) is developed to test the discrete simulation model and to show the influence of input data over the results obtained through simulation. For input data is used the probability distribution function to introduce in simulation the randomly character of cargo flows. We use Exponential distribution with parameter λ, the interval between arrival. For process duration we use Normal distribution with parameters [mean, variance] The input data are presented in Table 1.

Table 1 Input data of simulation scenarios [hours]

Scenarios	Input train flows from maritime port hinterland	Input wagon sets from maritime terminals	Technical inspection process duration	Commercial inspection process duration	Technological activity duration	Shunting process duration
S1	Exponential (1)	Exponential (1)	Normal [0.4,0.03]	Normal [0.4,0.03]	Normal [0.4,0.03]	Normal [0.4,0.01]
S2	Exponential (1)	Exponential (1)	Normal [0.6,0.05]	Normal [0.6,0.05]	Normal [0.6,0.05]	Normal [0.4,0.01]
S3	Exponential (0.7)	Exponential (0.7)	Normal [0.3,0.03]	Normal [0.3,0.03]	Normal [0.3,0.03]	Normal [0.4,0.01]
S4	Exponential (1)	Exponential (1)	Normal [0.25,0.03]	Normal [0.25,0.03]	Normal [0.25,0.03]	Normal [0.5,0.03]
S5	Exponential (1)	Exponential (1)	Normal [0.4,0.03]	Normal [0.25,0.03]	Normal [0.25,0.03]	Normal [0.5,0.03]
S6	Exponential (1)	Exponential (1)	Normal [0.4,0.03]	Normal [0.4,0.03]	Normal [0.25,0.03]	Normal [0.6,0.5]
S7	Exponential (1)	Exponential (1)	Normal [0.4,0.03]	Normal [0.4,0.03]	Normal [0.4,0.03]	Normal [0.6,0.5]

The resources of shunting yard used are presented in Table 2. The activity made in Departure Tracks are made using specialized staff. The commercial aspects are solved by staff with economic background. The technical inspection it is made by railway inspectors to identify possible technical problems. The release of the wagons and the deactivation of the braking system is performed by certified workers. To increase the processing capacity, all these employees are grouped in teams that can work independently.

Table 2 The discrete simulation model resources

Scenarios	Number of tracks	Number of teams for technical inspection	Number of teams for commercial inspection	Number of teams for technological activity	Number of humps
S1	3	2	2	2	1
S2	3	2	2	2	1
S3	3	2	2	2	1
S4	3	1	1	1	1
S5	3	2	1	1	1
S6	3	2	1	1	1
S7	3	2	2	1	1

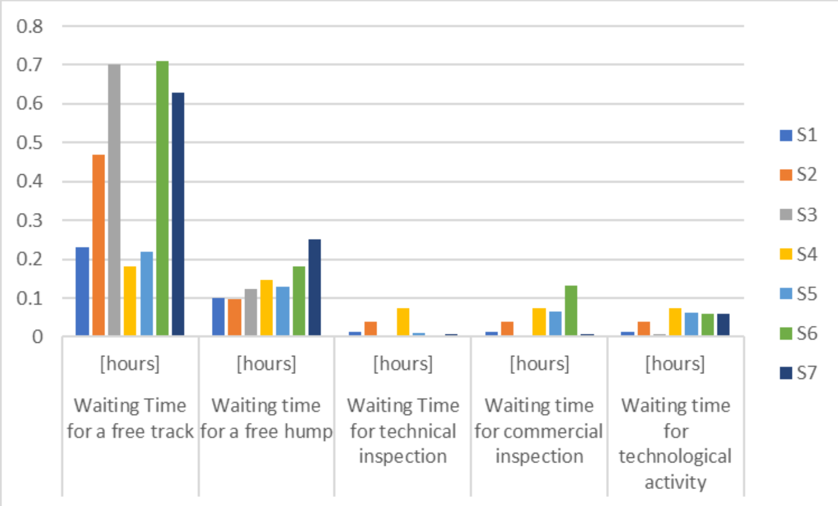
After the running time, for a period of 180 days of the simulation model a set of serving attributes are obtained. The values obtained for the proposed scenarios are presented in Table 3.

Table 3 The results obtained through discrete simulation model.

Scenarios	Waiting time for a free track [hours]	Waiting time for a free hump [hours]	Waiting time for technical inspection [hours]	Waiting time for commercial inspection [hours]	Waiting time for technological activity [hours]	The number of transit trains and wagon sets	The usage of hump [%]
S1	0.23	0.100	0.014	0.013	0.014	17303	42
S2	0.47	0.097	0.038	0.039	0.039	17156	47
S3	0.70	0.123	0.005	0.005	0.006	24568	64
S4	0.18	0.145	0.073	0.073	0.073	17363	49
S5	0.22	0.128	0.011	0.065	0.063	17111	53
S6	0.71	0.181	0.005	0.133	0.058	16993	70
S7	0.63	0.250	0.006	0.006	0.059	17234	70

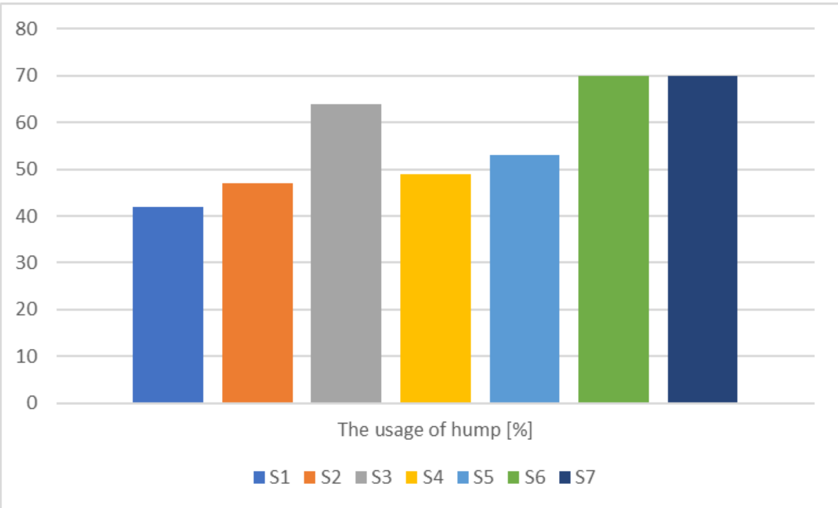
Considering S1 as base scenario the change of input data and the number of simulation model resources induces some variations of the obtained results. Through simulation are obtained values for trains and wagon sets waiting time for a free track and for a free processing team. For example, in scenario S2 the process duration for technical inspection, commercial inspection and technological activity is increased with 50%. In scenario S3 is reduced the time interval between the arrival moments of the entities in parallel with a reduction by 25% of process duration made in Receiving Tracks area. The results show an increasing value of waiting time for a free track from an average value of 0.23 hours to 0.70 hours.

The set of scenarios S4-S7 are characterized by a reduction of the number of teams allocated to Receiving Tracks area for the process (technical inspection, commercial inspection, technological activity) in parallel with variations of process duration. A reduction of this period with 37% and of the number of allocated teams from two to one allows the transit of the almost the same number of trains and wagon sets in 180 days (the simulation period) 17303 in scenario S1 versus 17363 in scenario S3, but the waiting time for a free track is reduced with 21%. This reduction is important because the waiting time is supported by the rail infrastructure from maritime terminals and from land network. The results of waiting times counted through simulation model are shown in Graph 1:



Graph 1 Waiting Time

The increasing of the period for shunting process from an average value of 0.4 hours to 0.6 hours (following a Normal distribution function) conduces to a better usage rate of hump from 42 [%] to 70 [%] but with an increase of waiting time for a free hump with 81-150 %. The usage rate of hump for all seven scenarios is shown in Graph 2:



Graph 2 The usage of hump

The previous graphs show the influence of aleatory aspect of input flows and duration of technological process on serving parameters. The waiting time for a free track can have a large variation if the number of the team is reduced. The waiting time for a free hump is not influenced by this aspect because the duration of shunting process is fixed. In practice this can be improved by using simultaneous shunting process if the hump has two tracks. The authors have preparing a research in this direction and will be disseminated in future.

6. CONCLUSIONS

The evaluation of the activity inside of port shunting yard is important in solving decisional problems of the main actors implicated in logistics chain with a maritime component. The restrictions induced by a limited storage capacity inside the maritime terminals and a restricted schedule of train traffic on land network are part of the decision-making process. For a correct analysis is necessary to have a tool to simulate possible scenarios in the activity of port shunting yards. The discrete simulation model allows to recreate the activity of a maritime shunting yard in a virtual space. Dedicated software for simulation as Arena Rockwell can be used to create a model using logical blocks. The input data can be changed for different scenarios and the serving parameters are counted as results of simulation. The decisional process is sustained with numeric values and quality parameters obtained through simulation model.

The results obtained through simulation model on our hypothetical shunting yard show the importance of input flow in reducing the waiting time before specific process made in Departure Tracks. Because the railway network and maritime terminals works with regulated access a coordination between these entities can lead to a reduction of the analysed waiting times.

Our future goal is to develop methodology for calibrating a discrete simulation model developed for the case of a maritime shunting yard using specific data from maritime transport domain. Another future goal is to develop simulation model for the case of shunting yard with simultaneous shunting process.

REFERENCES

[1] Abdirassilov, Z., Sladkowski, A.: Application of artificial neural network for short-term prediction of container train flows in direction of China-Europe via Kazakhstan. Transport Problems, 2018, Vol 4, Issue 4, pp. 103-113.

[2] Abramovic, B., Zitricky, V., Biškup, V.: Organisation or railway freight transport: case study CIM/SMGS between Slovakia and Ukraine. European Transport Research Review, 2016, Vol 8, No 27, pp. 1-13.

[3] Antognoli M., Capodilupo L., Marinacci C., Ricci, S. Present and Future Operation of Rail Freight Terminals – Studies in Systems, Decision and Control, 2018, Vol. 155.

[4] Adlbrecht, J.A., Hüttler, B., Ilo, N., Gronalt, M. Train routing in shunting yards using Answer Set Program-ming, Expert Systems with Applications, 2015, Vol 42, No 21, pp 7292-7302.

[5] Boysen, N., Fliedner, M., Jaehn, F., Peschl, E., Shunting yard operations: Theoretical aspects and applications, European Journal of Operational Research, 2012, Vol. 220, No 1, pp. 1-14.

[6] Capodilupo L, Furiò Pruñonosa S., Marinacci C., Ricci S., Rizzetto L. – Analytical methods and simulation models to assess innovative operational measures and technologies for rail port terminals: the case of Valencia Principe Felipe terminal XII Conference on Transport Engineering CIT 2016, Valencia, 2016.

[7] Jaehn, F., Michaelis, S. Shunting of trains in succeeding yards, Computers & Industrial Engineering, 2016, Vol. 102, pp. 1-9.

[8] Jaehn, F., Rieder, J., Wiehl, A. Single-stage shunting minimizing weighted departure times, Omega, 2015, Vol 52, pp. 133-141.

[9] Javadian, N., Sayarshad, H., Najafi, S. Using simulated annealing for determination of the capacity of yard station in a railway industry, Applied Soft Computing, 2011, Vol. 11, pp. 1899-1907.

[10] Krile, S., Maiorov, N., Fetisov, V., Forecasting the operational activities of the sea passenger terminal using intelligent technologies, 2018, Transport Problems, Vol. 13.

[11] Krile, S., Application of the minimum cost flow problem in container shipping. In Proceedings. Elmar-2004. 46th International Symposium on Electronics in Marine, 2004, pp. 466-471.

[12] Monnier, N., Gheorghe, A., Quantitative Risk Assessment of Hazardous Materials Transport Systems (Dordrecht, Kluwer Academic Publishers), 1996

[13] Popa, M., Rosca, E., Rusca, F. On transport network reliability. Transport Problems, 2012, Vol. 7, Issue 3. pp. 127-134.

[14] Rusca, F., Popa, M., Rosca, E., Rusca, A., Capacity analysis of storage area in a maritime container terminal. In Maritime Technology and Engineering III: Proceedings of the 3rd International Conference on Maritime Technology and Engineering (MARTECH 2016, Lisbon, Portugal, 4-6 July 2016), 2016, pp. 92-99.

[15] Rusca, F., Popa, M., Rosca. E., Rusca, A., Simulation model for maritime container terminal Transport problems, 2018, Vol. 13, Issue 4, pp. 47-54.

[16] Rockwell ARENA 12 Simulation Software

[17] Sculli D., Hui C.F., Three-dimensional stacking of containers. Omega, 1998, Vol. 16,, pp. 585–594.

[18] Steenken D, Voß S and Stahlbock R 2005 Container Terminals and Automated Transport Systems (Berlin: Springer) p 3-49

[19] Taleb-Ibrahimi M., De Castilho B. & Daganzo C.F. 1993. Storage space vs handling in container terminals. Transport Res B 27, pp. 13–32

CHALLENGES OF MARITIME HIGHER EDUCATION-MEETING THE QUALITY REQUIREMENTS

Merica Slišković
Pomorski fakultet u Splitu, Sveučilište u Splitu
Split, Croatia
E-mail: merica@pfst.hr

Ana Perić Hadžić
Pomorski fakultet u Rijeci, Sveučilište u Rijeci
Rijeka, Croatia
E-mail: ana.peric@pfri.uniri.hr

Anita Gudelj
Pomorski fakultet u Splitu, Sveučilište u Splitu
Split, Croatia
E-mail: anita.gudelj@pfst.hr

Helena Ukić Boljat
Pomorski fakultet u Splitu, Sveučilište u Splitu
Split, Croatia
E-mail: hukic@pfst.hr

UDK 378:656.61

Summary

Strengthening and unification of professional and technical capacities, together with the standardization of qualifications and competitive courses of study will lead to a higher level of quality in maritime education. Only qualified and well-educated seafarers can contribute to the sustainable development of maritime transport. The aim of this paper is to present the current situation regarding the standardization of qualifications and educational programs in the field of maritime higher education in Croatia. External evaluation of the quality system in maritime higher education institutions is periodically carried out by several organizations. The most frequent evaluation is performed by accredited evaluators according to the standards of ISO. Every five years, maritime higher education institutions are also evaluated by European Maritime Safety Agency and the Agency for Science and Higher Education. This paper aims to provide an overview of the second element of the project MEDUSA entitled - Enhancing Quality Assurance of Higher Education. The overall project objectives are to enhance the performance and international attractiveness of maritime higher education, to increase the quality of higher education in maritime affairs and to promote the principles of smart, sustainable, and inclusive development. Special reference is made to the results of the recent procedures for the accreditation of maritime faculties in Croatia by the Agency for Science and Higher Education. The re-accreditation procedure was carried out in accordance with the requirements of the "Standards and Guidelines for Quality Assurance in European Higher Education", considering international practice in the field of quality assurance in science and higher education. The essential and generally accepted standards in higher education are assessed. The recommendations and assessments of the re-accreditation can serve as input for quality improvement.

Keywords: Maritime higher education; MEDUSA project; Quality assurance; Re-accreditation; Standards

1. INTRODUCTION

One of the key elements of sustain maritime industry should be well trained and educated seafarers. Now, based on data available from International Chamber of Shipping 1.647,500 seafarers are employed [11].

As world economy and consequently the world trade grows, adequately trained and qualified maritime industry professionals with the more specific knowledge and skills will be needed [4]. According to the BIMCO 2016 report additional 147,500 officers by 2025 would be needing [3]. While newst study reviled that global demand for seaferers is estimated at 1,545,000 or aproximately 790,500 officers [9].

Training and education of seafarers is based on international conventions such as Standards of Training, Certification and Watchkeeping of Seafarers (STCW Convention), but also flexible to all necessary updates in order to meet new technical demands and educate modern seafarers. To sustain certain level of quality in knowledge and skills uniformity and coordination between maritime education faculties is needed. Continuous improvement and unification of maritime courses of study, together with the standardization of qualifications will lead to a higher level of quality in maritime education.

Standards and Guidelines for Quality Assurance in European Higher Education (ESG) contains the Standards for Quality Assessment, which are used to assess compliance with Key Standards and to assign a grade to the quality of a higher education institution [1].

1.1. Maritime education standard in shipping and ship management project

Project titled Maritime education standard in shipping and ship management - MEDUSA follow the results of the previous Croatian Qualification Framework (CROQF) project KIKLOP. The aim of the KIKLOP project was screening of labour market needs in maritime transport and logistics, and recognising new skills and competencies that should be integrated in maritime study programmes [13]. Trough KIKLOP many new maritime markets and new competence requirements have been identified which are not included in existing curricula. Prior investigation of labour market needs in the maritime sector has seen the transformation of the Croatian maritime market and the strong specialisation of maritime and marine shipping resulting in changes in the structure of employers, the development of small business, the development of new jobs and activities and consequently new requirements regarding specific skills and competences. To ensure a high quality, efficient and innovative higher education in the long term the MEDUSA project will adapt the educational offer to modern labour market needs in the maritime domain. Project leader University of Rijeka, Faculty of Maritime Studies together with its partners University of Split, Faculty of Maritime Studies, University of Zadar, Maritime Department, Croatian Association of Sips Agents, Zorović Maritime, Seaquest Ship management, Express, Bureau Veritas Croatia, Viktor Lenac Shipyard, Jadrolinija have been conducting the project through 30 months started in March 2019. The activities described on Figure 1. will contribute to the realisation of project outcomes [5].

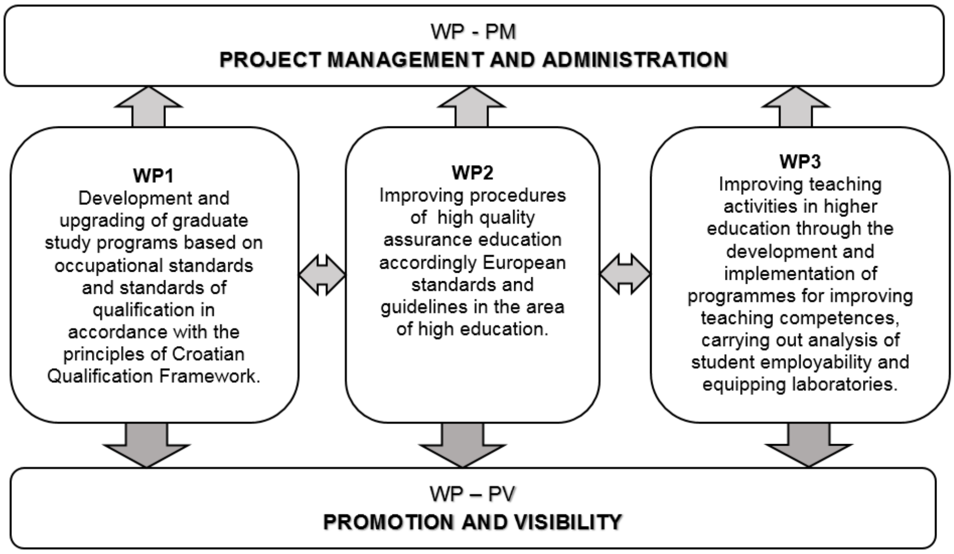


Figure 1. Work packages of the project MEDUSA

Furthermore, this project will overcome the limited availability of funding for the application of the CROQF principles [12] and ESG guidelines and will directly implement the guidelines in the development of new study programs at maritime faculties, thus creating the integrity of the CROQF principles and ensuring continuous improvement of quality, relevance, and efficiency of higher education in the maritime domain. The project also contributes to the fulfilment of the goals of the Smart Specialization Strategy of the Republic of Croatia [8] for the period from 2016 to 2020 where transport and mobility are identified as a thematic priority area and the goals of the Education, Science and Technology Strategy for the period 2014-2020 in the section: Improving study programs [7]. The project is harmonized with the Maritime Development Strategy and Integrated Maritime Policy of the Republic of Croatia 2014-2020, which defines the directions of maritime development and the promotion of Croatia as an international centre of excellence for maritime education [6].

2. QUALITY ASSURANCE

Quality assurance system (QAS) is a STCW requirement and should be a natural and integral part of any higher education management system, as it enables users to have confidence in the quality of internal processes and the performance of study programs. Quality assurance is the process of monitoring and evaluating all activities of the higher education institution (study programs, teaching process, student support, support for students from underrepresented and vulnerable groups, learning resources, scientific activity, etc.) consistently and sustainably to meet the end users. It should be supported by relevant documents.

Quality is a crucial factor in equipping students with the knowledge, skills, and competencies to be successful upon graduation. In addition, QAS provides concrete and comprehensive feedback on the execution of processes/goals and the satisfaction and expectations of stakeholders.

Thus, the purpose of QAS is to sustain and improve the quality of higher education, to achieve the vision and mission, and to meet the needs of stakeholders (students, teachers, professional staff, community, labor market, employers, etc.). QAS establishes quality measures and indicators that are aligned with recognized quality standards and also help to ensure consistency in decisions made by faculty management, accreditation bodies, and audits.

Croatian higher education institutions are developing their QAS to support processes and use various tools to improve the quality of the offered study programs, teaching and learning process and research work, according to the various models such as:

- the European Foundation for Quality Management (EFQM), International Organization for Standardization (ISO), CRQQE
- institution-specific, but follows national QA frameworks and guidelines.

For efficient and safe maritime transport, the knowledge and skills of seafarers are crucial and important. As maritime transport is generally international, seafarers' knowledge and skills need to be defined in uniform standards for competencies and certification. The International Maritime Organization (IMO) has adopted the STCW Convention and prescribed the minimum qualifications of seafarers.

As education is part of the public sector, many Maritime Education Institutions (MEIs) adopt the European Quality Management tool for the Public Sector in fusion with the requirements of the STCW Convention to meet IMO requirements and the requirements of the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG) produced by European Association for Quality Assurance in Higher Education (ENQA). MEIs are responsible for ensuring the ongoing quality of the programs and services they offer to students.

From another side, each MET institution must be accredited by an authorized professional or government body, either nationally or internationally, to ensure that an ongoing high standard of quality is maintained. This fusional quality model allows for a quantitative assessment of MEIs.

Each MEI could choose a quality system appropriate to its institution. It should be noted that Croatian maritime higher education institutions have adopted the quality assurance system based on the CRQQE and the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG), as well as the requirements of ISO 9001:2015. Meeting the requirements of the ESG as well as the requirements of ISO 9001 can help to ensure the effectiveness of the internal quality assurance system for these institutions.

The ESG standards for Higher Education Institution created as a priority for education in universities, can also serve the area of non-formal education and the standards and guidelines are divided into the following areas (EUA, 2009):

ESG 1.1 Policy for quality assurance
ESG 1.2 Design and approval of programmes
ESG 1.3 Student-centred learning, teaching and assessment
ESG 1.4 Student admission, progression, recognition, and certification
ESG 1.5 Teaching staff
ESG 1.6 Learning resources and student support
ESG 1.7 Information management
ESG 1.8 Public information
ESG 1.9 On-going monitoring and periodic review of programmes
ESG 1.10 Cyclical external quality assessment

University of Rijeka, Faculty of Maritime Studies University of Split, Faculty of Maritime Studies, University of Zadar, Maritime Department, which are the partners of the Medusa project, have developed the internal quality assurance system as integral part of the university QA framework (Figure 2).

A successful university quality assurance framework is guided by:

- The pursuit of continuous improvement;
- A focus on learning;
- The need to involve all functions and units of an institution;
- Accountability and transparency;
- The documentation and implementation of policies, guidelines and procedures.

The quality management system must be included in the quality assurance of the MEI. The norm ISO 9000 is recognized as an appropriate approach for the establishment and development of a quality management system in the Croatian Maritime Education Institutions due to its international standards and reflection of sustainability.

The ISO (International Organization for Standardization) develops and publishes international standards and guidelines that can be used to ensure that resources, products, processes, and services are fit for purpose.

Regarding the quality functions of the Quality Management system of MEI, the following functions can be identified:

- Increase loyalty of all stakeholders,
- Promoting a culture of quality and continuous improvement and innovation,
- Laying the foundations for organizational excellence,
- Reducing relevant costs and resource consumption
- Identifying potential risks in meeting the set objectives and avoiding negative consequences.

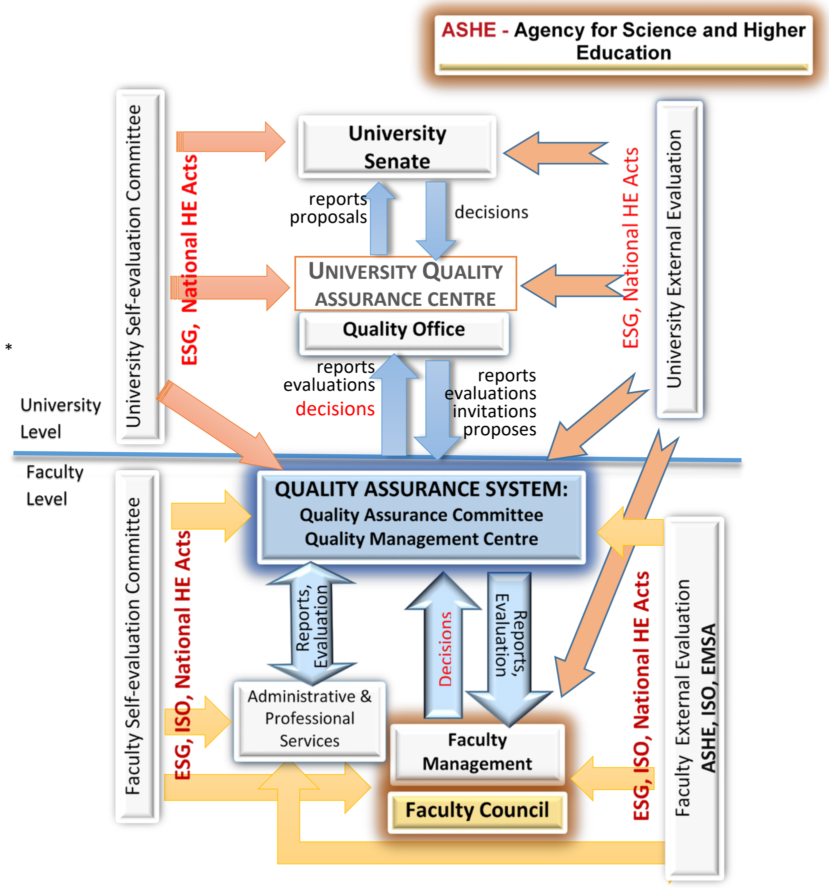


Figure 2 University Quality Assurance System

The quality assessment of maritime higher education institutions must be a combination of internal and external assessments. The results achieved and processes within the institution are assessed using indicators adapted for Higher education institutions (HEIs) (Figure 3). Internal quality assessment is carried out by an internal self-evaluation committee and should follow the principles and rules of self-evaluation in accordance with the ESG guidelines and the requirements of ISO. At the Faculty of Maritime Studies, internal quality assessment is carried out in accordance with the policy, which integrates the requirements of ESG and ISO standards. In order to clarify the linkage of ISO 9001:2015 with the ESG standards, Quality Assurance Committee of the Faculty Maritime Studies in Split developed a cross matrix (Table 1) [10].

Croatian universities have their own internal quality evaluation and self-evaluation committee. During the evaluation process, the University Self-Evaluation Committee cooperates with the Faculty Self-Evaluation Committee and evaluates the university as its component only according to the ESG standards.

The external quality evaluation must be covered by a recognized and accredited body. Through mechanisms such as accreditation, validation and peer review, continuous quality improvement is demonstrably ensured. Every five years, Croatian MEIs must go through the accreditation process conducted by Croatian Agency for Science and Education. The international body assesses the institutions in accordance with the ESG standard. Annually, MEIs are audited by ISO.

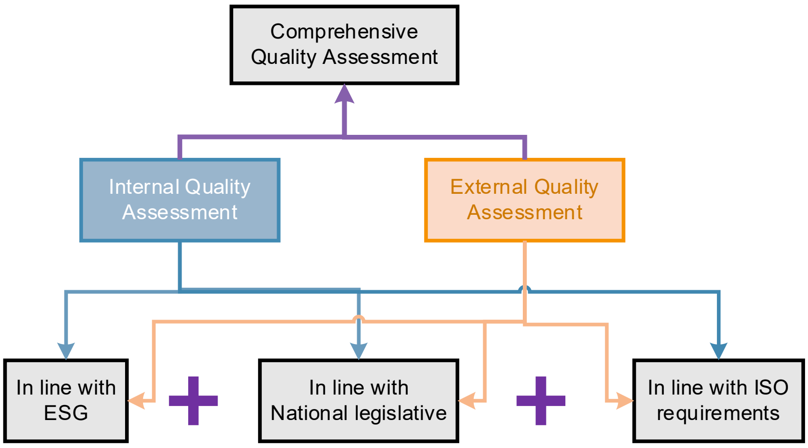


Figure 3 Quality Assessment Framework

Table 1 Correspondence between ESG standards and ISO 9001:2015

ESG Standards / Chapters ISO 9001	Policy for quality assurance	Design and approval of programmes	Student-centred learning, teaching and assessment / Student admission, progression, recognition and certification	Teaching staff	Learning resources and student support	Information Management	Public information	On-going monitoring and periodic review of programmes	Cyclical external quality assessment
Quality Management System	+								
Management Responsibility	+								
Resource Management				+	+	+			
Realization		+	+		+	+	+	+	
Measurement, Analysis and Improvement	+					+			+

Source: Quality Assurance Manual, University of Split, Faculty of Maritime Studies, 2019 [10]

3. ACCREDITATION OF MARITIME FACULTIES IN CROATIA

The study programmes of Maritime Faculty in Split (PFST), as well as the programmes of Maritime Faculty in Rijeka (PFRI), are in line with the mission and strategic goals of the higher education institution and the needs of the society. These programmes educate for the national and international labour market, considering the recommendations of the professional associations that monitor their licencing. The re-accreditation procedure was carried out in accordance with the requirements of the ESG considering international practice in the field of quality assurance in science and higher education.

The standards are divided into five sections, and each section is further divided into subsections as follows:

I. Internal quality assurance and the social role of the higher education institution (ESG 1.1, ESG 1.7, ESG 1.8).
II. Study programmes (ESG 1.2, ESG 1.9)
III. Teaching process and student support (ESG 1.3, ESG 1.4, ESG 1.6)
IV. Teaching and institutional capacities (ESG 1.5, ESG 1.6)
V. Scientific/artistic activity

The last re-accreditation of maritime faculties in Croatia was carried in 2018 by the Agency for Science and Higher Education. The results in section *II Study programmes* are presented in Table 2.

Table 2 Overview of quality grade standards for section II Study programmes

II. Study programmes	Unsatisfactory level of quality	Minimum level of quality	Satisfactory level of quality	High level of quality
2.1. The general objectives of all study programmes are in line with the mission and strategic goals of the higher education institution and the needs of the society.			PFRI PFST	
2.2. The intended learning outcomes at the level of study programmes delivered by the higher education institution are aligned with the level and profile of qualifications gained.		PFRI	PFST	
2.3. The higher education institution provides evidence of the achievement of intended learning outcomes of the study programmes it delivers.		PFRI	PFST	
2.4. The HEI uses feedback from students, employers, professional organisations and alumni in the procedures of planning, proposing and approving new programmes, and revising or closing the existing programmes.			PFRI PFST	
2.5. The higher education institution ensures that ECTS allocation is adequate.			PFRI PFST	
2.6. Student practice is an integral part of study programmes (where applicable).			PFRI PFST	
2.7. Lifelong learning programmes delivered by the higher education institution are aligned with the strategic goals and the mission of the higher education institution, and social needs.				PFRI PFST

Source:https://www.azvo.hr/hr/vrednovanja/postupci-vrednovanja-u-visokom-obrazovanju/reakreditacija-visokih-ucilista/rezultati-vrednovanja-rvu [2]

However, from the analysis of the external evaluators, there are further recommendations for improvement of the study programmes and the teaching process. There is a necessity for improvement of existing study programmes at the level of learning outcomes and assessment methods, professional practise, and development of new study programmes which are aligned with labour market needs. There is also a need for a greater internationalisation of existing study programmes for the purpose of better cooperation with the European academic community.

4. CONCLUSION

Improvement of study programs, their attractiveness, students' satisfaction, teachers' training, provision of sufficient resources for learning are nowadays inevitable elements of high standards and requirements imposed on scientific and educational institutions. At the same time, the implementation of CROQF projects provided an opportunity for serious systematic reflection on the quality, efficiency, and innovation of education by anticipating changes in the labour market. The improvement of existing study programs to meet the needs of the labour market for highly qualified personnel in the implementation of innovative economic activities, as well as the continuous institutional development, lead to quality, efficient and innovative education. At the same time, the CROQF methodology requires the standardization of qualifications for the study programs that are interconnected, which is an additional problem of harmonization at the national level.

Quality assessment of maritime higher education institutions in Croatia is a combination of internal assessment by an internal self-assessment committee and external assessment by a recognized and accredited body. After each assessment, some corrective actions can be taken, which can serve as input for quality improvement.

As the maritime industry plays a decisive role in international trade and business, one of the key factors is and must be the sustainable training of seafarers. In addition to standardization at the national level, standardization, and unification of maritime higher education at the international level is a crucial element. Greater internationalization of existing courses of study can be a first step towards sustainable maritime education.

Acknowledgements

This research was supported by the Faculty of Maritime Studies Rijeka through the project MEDUSA Maritime Education Standard in Shipping and Ship Management.

REFERENCES

[1] AZVO, Standards and Guidelines for Quality Assurance in European Higher Education, https://www.azvo.hr/images/stories/novosti/ENG_STANDARDS_FOR_THE_EVALUATION_OF_QUALITY_-_UNIVERSITIES.pdf (acessed 15.6.2021)

[2] AZVO, Postupci vrednivanja u visokom obrazovanju, https://www.azvo.hr/hr/vrednovanja/postupci-vrednovanja-u-visokom-obrazovanju/reakreditacija-visokih-ucilista/rezultati-vrednovanja-rvu (acessed 20.5.2021.)

[3] BIMCO (2016). BIMCO/ICS [International Chamber of Shipping] manpower report predicts potential shortage of almost 150,000 officers by 2025. (acessed 17.5.2021.)

[4] https://sustainabledevelopment.un.org/content/documents/1163CONCEPT%20OF%20%20SUSTAINABLE%20MARITIME%20TRANSPORT%20SYSTEM.pdf (acessed 20.5.2021.)

[5] MEDUSA projekt, http://www.medusa-project.eu/o-projektu/ (acessed 20.5.2021.)

[6] Ministarstvo pomorstva, prometa i infrastrukture.Strategija pomorskog razvoja i integralne pomorske politike Republike Hrvatske 2014-2020, Zagreb 2014. http://www.mppi.hr/UserDocsImages/Strategija_pom_razvitka%20_uz_odluku_289.pdf (acessed 20.5.2021.)

[7] Ministarstvo znanosti, obrazovanja i sporta, Strategija obrazovanja, znanosti i tehnologija, Narodne novine Republike Hrvatske, br. 124,2014., http://narodne-novine.nnhr/clanci/sluzbeni/2014_10_124_2367.html (acessed 20.5.2021.)

[8] Strategija pametne specijalizacije Republike Hrvatske za razdoblje od 2016. do 2020. godine, Narodne novine Republike Hrvatske, br. 32, 2016., https://narodne-novine.nn.hr/clanci/sluzbeni/dodatni/439965.pdf (acessed 20.5.2021.)

[9] Shipping Fact: Global Supply and Demand of Seafarers, Maritime post from May, 2020 https://themaritimepost.com/2020/05/21/shipping-fact-global-supply-and-demand-of-seafarers/ (acessed 10.7.2021.)

[10] Quality Assurance Manual, University of Split, Faculty of Maritime Studies, 2019. http://www.pfst.unist.hr/images/dokumenti/kvaliteta/Prirucnik_Kvaliteta_PFST.pdf (acessed 27.5.2021.)

[11] UNCTAD (2020). Review of Maritime Transport 2019.https://unctad.org/system/files/official-document/rmt2019_en.pdf (acessed 20.5.2021.)

[12] Zakon o Hrvatskom kvalifikacijskom okviru, Narodne novine Republike Hrvatske, br. 20, 2021. https://www.zakon.hr/z/566/Zakon-o-Hrvatskom-kvalifikacijskom-okviru (acessed 20.5.2021.)

[13] https://www.pfri.uniri.hr/web/hr/projekti/arhiva/2015_-_KIKLOP_-_hr.pdf (acessed 10.7.2021.)

THE NAVIGATION IN ANCIENT TIMES AND THE MATHEMATICS

Tatjana Stanivuk
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: tstanivu@pfst.hr

Stipe Galić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: stipe.galic@pfst.hr

Ladislav Stazić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: lstazic@pfst.hr

UDK 51:656.61.052

Summary

Mathematics is present in the navigation since the first man tried to sail on the water. The calculations behind the sailing at the beginning was basic, just simple logic was enough to finish it. Calculation complexity changed in time, making it more and more complex and difficult. Navigational aids changed together with the calculation complexity, becoming more and more complex, showing improvements of the human different understandings of maritime matter. The paper presents the use of mathematics in ancient times and the relevant impact onto contemporary navigation.

Keywords: mathematics, navigation, depth sounding, Earth circumference, speed log

1. INTRODUCTION

Man went to sea in ancient times, and some 40,000 years ago the first sailors sailed the sea passage between New Guinea and Australia. For this voyage a little longer than 110 miles, one had to have the ability and knowledge of orientation, as well as a certain knowledge of navigation. As these two lands are not visible to each other [14], the venture of these first sailors gains even more weight. Navigation is a word that comes from the Latin language where it reads "*navigatio*" and is a compound of the Latin words "*navis*" (ship) and "*agere*" (to drive) [20]. By simply combining these two words, the definition of the word navigation is created, it describes the knowledge or science of the movement of a ship. Navigation is the skill or knowledge of guiding a ship from one place to another, choosing the most favourable route, and using achievements in technology and science, especially in mathematics, astronomy, geography, oceanology, meteorology,...

Mathematics as one of the fundamental sciences was and is one of main pillars of the navigation [21]. One can argue that the mathematics was in use even before the man attempted to use the astronomy, geography, oceanology, meteorology,…

First attempts of the navigation are linked to the terrestrial, near shore navigation [6], [12]. In that navigation the most important thing is to make sure that there is always enough sea water under the keel. Oleson wrote in his paper [19] that one of the best examples of the assuring of the enough sea water under the keel is written in the Bible (acts 27, 27-29): "*On the fourteenth night we were still being driven across the Adriatic Sea, when about midnight the sailors sensed they were approaching land. They took soundings and found that the water was a hundred and twenty feet deep. A short time later they took soundings again and found it was* *ninety feet deep. Fearing that we would be dashed against the rocks, they dropped four anchors from the stern and prayed for daylight.*" [13]. Some form of the depth sounding device was essential in the beginning stages of the navigation, other devices appeared much later.

One of those devices is speed measuring devices, basic device for the navigation. The other device is the speed metering device, or so called "the chip log". Both devices needed some sort of the mathematical knowledge, for the first one only basic measurement and logic, while the chip log required some calculations before development of the device.

The paper presents the mathematic which is hidden behind ancient navigational equipment, highlights hidden importance of the mathematics and shows its applications during the history.

2. FLOATING PRINCIPLE

First mathematical principle used in the history is the principle of the buoyancy. The buoyancy is the ability to float in water. Ancient man noticed that some object float in the water and used them to help them cross various waterways. The floating principle [2] is first formulated by Archimedes of Syracuse, ancient Greek mathematician, astronomer, engineer and inventor. He is famous for several advancements in the mathematics, as well as for the development of the Archimedes' screw and setting the foundations of the fluid mechanics in the Archimedes' principle.

Archimedes' principle states that stating that a body submerged in a liquid s acted upon by an upward force. The magnitude of the force is equal to the weight of the liquid displaced by the body [15], [17].

Archimedes stated his principle using the mathematical equation:

$$F_b = -\rho g V \quad (1)$$

where:

F_b – buoyant force

ρ – density of the fluid

g – acceleration due to the gravity

V – volume of the fluid

Therefore, it can be assumed that ancient mariners used this principle without understanding the mathematical calculation which is needed to calculate buoyancy and load limits of all modern vessels.

3. DEPTH MEASUREMENT

The first depth gauges were ordinary weights tied with a rope (Figure 1) to measure the depth from the bow of a ship. This method of measurement could only be used for information, and the results were not systematically recorded and used.

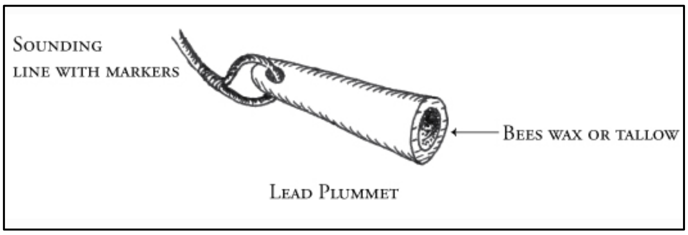


Figure 1 First type of depth measuring device

Source: [23]

This method of measuring depth (Figure 2) lasted a very long time and could be used up to a ship speed of 10 knots [8]. The oldest known weight is dated to the 7th century. It is made of bronze and has all the characteristics of later and more modern weights for measuring depth (showed on Figure 1). Its shape is cylindrical, and has a hole in the middle. The whole weight is made so that when it reaches the bottom it sinks into the mud. The sludge lags in the hole in the middle and in this way data on the type of bottom can be obtained.

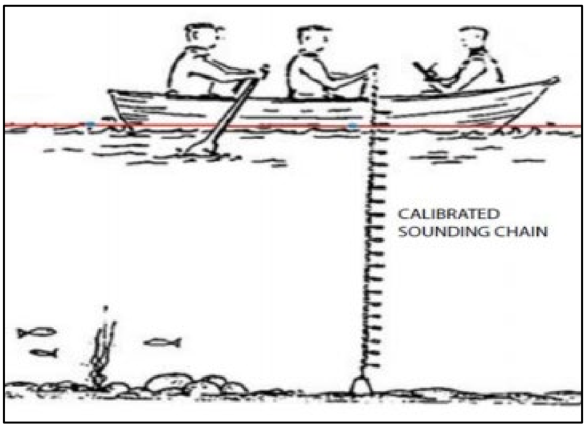


Figure 2 Depth measuring during the history device

Source: [11]

The systematic use of depth gauges coincides with the development of maps and navigation. Hydrographic measurements using primitive methods were very difficult and time consuming. Significant advances in depth measurements and data recording occurred only at the end of the 18th and the beginning of the 19th century, when depth measurements were performed in an organized and systematic manner. Development of the echo sounder and modern and widely available charts ended widespread use of this device.

The use of this device and its importance is already shown with the cite from the Bible. Another, very known example of the use of the depth measuring is given by very famous writer of children's books Samuel Langhorne Clemens. Majority of readers never heard of this name, but his pseudonym coming from measuring depth on the Mississippi is known to all. "*Mark Twain means the second mark on a line that measured depth, signifying two fathoms, or 12 feet, which was a safe depth for riverboats*" [24].

The use of the mathematics in this measurement is very simple, the personnel must know only two dimensions. First one is the "*d*" or draft (Figure 3), and the other one is the measured depth of the water "*l*".

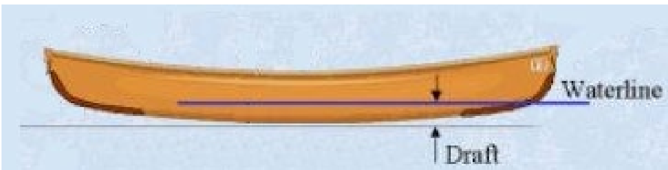


Figure 3 Definition of draft

Source: [7]

The draft is mostly non changing value; therefore, seaman must measure only the depth. Vessel should be in safe as long as the Equation 2 is valid:

$$d < l \quad (2)$$

where:
d – draft
l – depth of the water

Therefore, initial applications of the mathematics in the navigation purpose ended up to simple logic, there is no need for any calculation at all.

4. SPEED MEASUREMENT

In the very beginnings of sailing, speed measurements were performed by throwing of pieces of wood from the bow of a ship. As the ship was moving and the wood was not, the time it took for the ship to cover the distance until the tree remained at the stern was measured. This system had one major drawback, and that was that it could only be measured as many times as there were pieces of wood on board. The development of speedometers perfected this method and turned it into a system that was precise enough to determine the speed of a vessel. To develop accurate speed measuring device some mathematical calculations were needed.

4.1. Calculation of the Earth circumference

Calculation of the Earth circumference starts with Greek polymath Eratosthenes of Cyrene and 2nd century BC [5]. Eratosthenes of Cyrene calculated the circumference of the Earth using trigonometry and two assumptions, namely that the Earth is round and that the Sun is so far from the Earth that its rays can be taken as parallel directions. The measurement of the circumference of the Earth was based on the erroneous assumption that the city of Syene (present-day Asuán, Egypt) is located on the Tropic of Cancer and is located on the same meridian as Alexandria. He observed the Sun at the same time of year during the summer solstice on June 21st at noon, in two places which he assumed were on the same meridian (Syene and Alexandria) [10].

He observed water well in the Syene and there were no shadows in the well on midday on the first day of the summer. Eratosthenes concluded that the source of the rays is directly above the water well. He continued observation in Alexandria and by measuring the length of the gnomon established that rays are coming under the angle of the 7°12′ or 1/50th part of the circumference of a circle. Eratosthenes calculated Earth circumference using the Equation 3:

$$d : O = a : 360° \tag{3}$$

where:
d – the distance between Alexandria and Syena
O – Earth circumference
a – measured angle.

Military records from the time told him that the distance between cities is about 5000 stadia, the calculation showed that the Earth circumference is 250 000 stadia (Figure 4). Real accuracy of this calculation is hard to determine, there were several different values for a stadium in that time. If the stadium is assumed to be the Egyptian stadium (according to the experiment location), which is 157.5 metres, then the circumference can be calculated to a value of 39275 km, which is less than 2% of the target (exact value 40072 km).

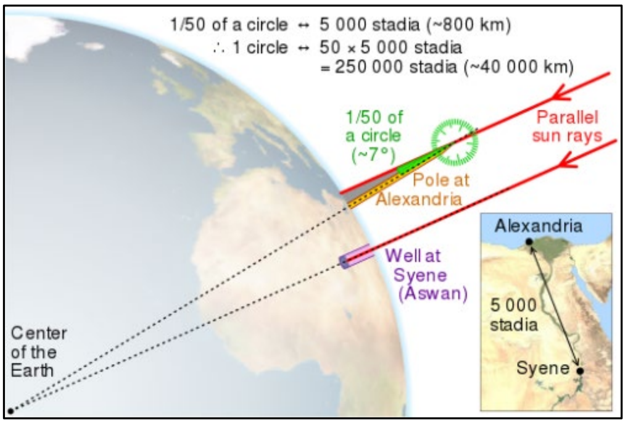


Figure 4 Eratosthenes calculation of the earth circumference

Source: [22]

As this result meant that the known part of the Earth was much smaller than the unknown, Eratosthenes was not believed and for the next 15 centuries people lived in the belief that the Earth was approximately three times smaller than it is [22]. One of examples of that wrong belief is Christopher Columbus. Although he studied what Eratosthenes wrote about the size of the Earth, nevertheless, based on Toscanelli's map, he decided to believe that the circumference of the Earth was 25% smaller. If, Columbus had accepted Eratosthenes' theory of the circumference of the Earth, he would have known that the place where he landed was not Asia, but the New World [9].

Further developments in the area are attributed to Willebrord van Royen Snellius and his work named Eratosthenes Batavus, published in 1617, containing his methods for measuring the Earth [4]. Following that measurement, the nautical mile was defined as one minute (of a degree) of latitude along any line of longitude and calculated to 6080.21 feet (1853.248) [16]. Snellius calculated the circumference using the triangulation, and in order to make these measurements accurately, he constructed a large quadrant by which he could accurately measure angles in tenths of a degree. This quadrant can still be seen today in the Boerhaave Museum in Leiden (Figure 5).

Figure 5 Quadrant of Snellius at Museum Boerhaave, Leiden

Source: [10]

All these researches led to precise calculation of the Earth circumference and to establishing the length of the nautical mile. In 1929 the nautical mile has been standardized by the First International Extraordinary Hydrographic Conference in Monaco as exactly 1852 metres or 6076.11 ft [18].

4.2. Speed log calculation

The speed log (Figures 6 and 7) consists of a light coil of thin rope 150 fathoms long (1 fathom is 1.8288 m). The whole coil is placed on a drum that can be easily rotated on pedestals. At the end of the rope, a speedometer plate was placed which would be thrown into the sea at the stern of the ship, so that the rope reached the first mark to the edge of the ship.

Figure 6 Chip log

Source: [1]

The hourglass would be turned at the same time (start measuring the time interval and release the speedometer rope). The rope would pay out until the time on the hourglass expires. Speed is then calculated upon the quantity of the rope is unwound from the drum. Conventional hourglasses for this purpose had an interval of 30 or 28 seconds and the rope was marked with knots that were evenly spaced.

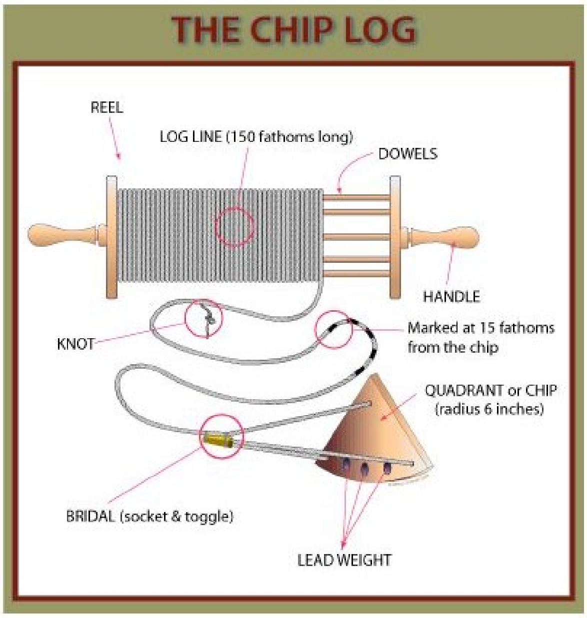


Figure 7 Chip log details

Source: [3]

The use of the mathematics in this measurement is little bit more advanced than previous, it requires some calculation. The construction of the chip log required basic mathematical knowledge and later the calculation of the Earth circumference which was used for the calculating the speed.

The mathematics behind the chip log theory starts with the known length of the mile and the length of measuring time. There were two different hourglasses one which was measuring 30 seconds and the other of 28 seconds. To calculate the distance between knots it was needed to solve simple Equation:

$$d = \frac{6080.21 * t}{3600} \quad (4)$$

Results of the calculation are presented in the Table 1.

Table 1 Distance between knots

Hourglass (t)	distance between knots (d)
30 sec	50ft 8in
28 sec	47ft 4in

The number of knots unwound from the drum gave a very good and accurate picture of the speed of the vessel in nautical miles per hour (measurement error was only about 1.5% [5]), and has remained today as a unit by which we measure the speed of a ship or aircraft.

5. CONCLUSION

Mathematics was used in solving problems in navigation while overcoming obstacles from the beginning of the maritime history, since man went to sea. Early developments are lost in the history, earliest preserved traces about navigation are ancient Greek navigation instructions dated to the 5th century BC. They measured the distance in stages (about 1/10 M); they orientated themselves well in the near-coastal navigation by means of characteristic natural and artificial objects on land (like lighthouses, temples or very prominent hills or stones), and sometimes on the open sea by celestial bodies and winds. Later in the Middle Ages, maritime science develops very fast mathematics played a major role in the advancement. In this time period, the application of astronomy in navigation is widely studied and starts to be applied. Development in the science changed main goal of the navigation, it was not enough to navigate safely, it become important to select the shortest possible route, i.e. the most economical route. This paper presented mutual dependency between mathematics and the navigation. From the very beginning of navigation, mathematics was used in calculating the speed of the ship and measuring the depths, items that are an integral part of sailing. In later historical periods the theoretical foundations of determining coordinates are developed, measurements are made, new methods of orientation are developed, all based on mathematics. From the above, it can be said that mathematics as a science and maritime as an activity are traced throughout history, and what they have in common is that they arise almost at the same time from human need. For this reason, it can be concluded that the development of mathematics has influenced the development of maritime affairs and all branches related to this activity.

Acknowlegments

This paper is inspired by the books written by captain Antun Ničetić PhD, and his research into the history of Dubrovnik and its very rich maritime history, which is addressed briefly in this paper as well.

REFERENCES

[1] Archipel International Maritime Gallery: Ship's Hand log with reel, chip and hourglass – ca. 1800, Zoelmond, The Netherlands, available at: https://archipel-img.com/object/handlog-with-reel-chip-and-hourglass-ca-1800/, accessed on 6th 03 2021

[2] Biddulph, F. and Osborne, R.: Pupils' ideas about floating and sinking, Research in Science Education, Vol. 14(1), pp. 114–124,1984, DOI 10.1007/bf02356797

[3] Bright hub engineering: Chip Log Explained - An Ancient Navigation System, available at: https://www.bright hubengineering.com/seafaring/60582-what-is-a-chip-log/, accessed on 6th 03 2021

[4] Britannica, The Editors of Encyclopaedia: "Willebrord Snell". Encyclopedia Britannica, 26 Oct. 2020, available at: https://www.britannica.com/biography/Willebrord-Snell, accessed on 6th 03 2021

[5] Casson, L.: The ancient mariners: seafarers and sea fighters of the Mediterranean in ancient times, Princeton University Press; 1991, ISBN: 0691014779.

[6] Emms, C.; Gossiff, S.: An Introduction to Coastal Navigation: A Seaman's Guide, Morgans Technical Books, 1992, ISBN: 0948254025

[7] Fuller, J.E.: Defining Ordinary and Natural Conditions for State Navigability Determinations, Arizona Geological Survey Contributed Report CR-18-B, 2018, 135p.

[8] Gould, R.A.: Archaeology and the social history of ships. Cambridge University Press; 2011, ISBN: 1139498169

[9] Gow, M.:Measuring the Earth: Eratosthenes and his celestial geometry(Great Minds of Ancient Science and Math), Enslow Publishing, LLC, New York, United States, 2009, ISBN: 0766031209.

[10] Haasbroek, N. D.: Gemma Frisius, Tycho Brahe and Snellius and their triangulations, 1968, Delft, the Netherlands

[11] Hamden, M.H.; Din, A.H.: A review of advancement of hydrographic surveying towards ellipsoidal referenced surveying technique, In: IOP Conference Series: Earth and Environmental Science, 2018, Vol. 169, No. 1, pp. 012019. IOP Publishing.

[12] Hofmann-Wellenhof, B.; Legat, K.; Wieser, M.: Navigation. Springer Science & Business Media; 2003, ISBN: 3211008284

[13] Holy Bible, New International Version, available at: https://www.biblegateway.com/passage/?search= Acts+27&version=NIV, accessed on 6th 03 2021.

[14] Kealy, S.; Louys, J.; O'Connor, S.: Least-cost pathway models indicate northern human dispersal from Sunda to Sahul. Journal of Human Evolution, 2018, Vol. 125, pp. 59–70. DOI: 10.1016/j.jhevol.2018.10.003

[15] Kireš, M.: Archimedes' principle in action, Physics Education, Vol. 42(5), pp. 484–487, 2007, DOI: 10.1088/0031-9120/42/5/006

[16] Löchstöer, J.: On the History of the Nautical Mile, The International Hydrographic Review, The Norsk Tidsskrift for Sjovesen, Horten, Norway, 1934.

[17] Mohazzabi, P.: Archimedes' Principle Revisited, Journal of Applied Mathematics and Physics, Vol. 5, pp. 836-843, 2017, DOI: 10.4236/jamp.2017.54073

[18] Moody, A.B.: The nautical mile, The International Hydrographic Review. 1950, pp 77-85.

[19] Oleson, J.P.: Ancient sounding-weights: a contribution to the history of Mediterranean navigation, Journal of Roman Archaeology, 2000, Vol. 13, pp. 293-310, DOI: 10.1017/S1047759400018948

[20] Richey, M.W.; Anderson, E.W.; Logsdon, T.S.; Jones, S.S.D.; Howard, J.L.; May, W.E.: "Navigation." Encyclopedia Britannica, January 29, 2021. Available at: https://www.britannica.com/technology/navigation-technology, accessed on 6th 03 2021.

[21] Stanivuk, T.; Galić, S.; Bojanić, M.: Mathematics as a Science and Marine Activity Follow Each Other Throughout History, Transactions on Maritime Science, 2017 Vol. 06(01), pp. 55-60, DOI: 10.7225/toms.v06.n01.006

[22] The Asian Age: Geosphere: Measuring the size of Earth, 2017, available at: https://www.asianage.com /science/160417/geosphere-measuring-the-size-of-earth.html, accessed on 14th 03 2021

[23] Tristão, N.: Fifteenth Century Tools for Navigation, in Crossing the ocean sea, available at: https://crossingthe oceansea.com/OceanSeaPages/OS-40-ToolsForNavigation.html, accessed on 6th 03 2021

[24] Waugaman, R.M.: Samuel Clemens and Mark Twain: Pseudonym as act of reparation, Psychoanalytic Review, 2010, Vol. 97(5), pp. 835-56, DOI: 10.1521/prev.2010.97.5.835

FAULT TREE ANALYSIS AS A REPLACEMENT FOR MANUFACTURERS MAINTENANCE INSTRUCTIONS

Ladislav Stazić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: lstazic@pfst.hr

Vlatko Knežević
University of Zadar
Split, Croatia
E-mail: vknezevi1@unizd.hr

Nikola Račić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: nikola.racic@pfst.hr

Josip Orović
University of Zadar, Maritime department
Zadar, Croatia
E-mail: jorovic@unizd.hr

UDK 004.414 : 621.313.1

Summary

During the analysis of numerous Computerized Planned Maintenance System, it is noted that one of the most frequent deficiencies is the lack of the maintenance plan created according to the manufacturer's recommendation. The reason for that deficiency usually is that the manufacturer's books and manuals were missing and there were no substitute methods provided. This article is giving a possible solution for a replacement source for inserting the missing data based on the fault tree analysis. The method is used to analyse and list all faults of the Main Engine turbocharger system. Equipment manufacturer instructions and relevant data from Computerized Planned Maintenance System are analysed in details. Data are compared with the FTA items to establish their similarity and to determine if FTA can be the replacement source for the planned maintenance creation.

Keywords: Failure tree analysis, Computerized Planned Maintenance System, Turbocharger, Maintenance

1. INTRODUCTION

CPMS (Computerized Planned Maintenance System) [6] is a form of a computerized program used for management of the Planned Maintenance. The Planned Maintenance is a form of maintenance strategy where all works, activities and costs are planned in advance. CPMS have several different sources for the construction of the database [7],:

- manufacturers' recommendations and specifications,
- analysis and measurements (i.e., lube oil analysis, vibration analysis),
- the company experience in the operation and maintenance of the ship and its machinery.

Manufacturers' recommendations and specifications are listed in the first place because they represent the main source and a big majority of planned works are coming from it. This team noted that during several years of the research into the quality of the CPMS databases one deficiency frequently appeared; a negative answer on the 8th question of the Computerized PMS database evaluation questionnaire [14]: *"Do all devices in the DB have linked maintenance plan according to manufacturer's recommendation?"*. This deficiency often occurred when the vessel was purchased as used when the equipment manual was missing. The database development team didn't know or ignored that fact and the shipowner (or team responsible for final database control) also. In some cases, when both parties were informed that certain equipment was missing from the database, the answer predominantly was that the manufacturer's books and manuals were missing. If the argument is accepted as valid, then both sides should ask whether there is a solution to this problem?

The reliability of an engine or a system is one of the key characteristics which regulates all aspects of the construction and maintenance. The reliability in operation dictates the future performance of an engine or system as well as the design and scheduling of the maintenance operations. Numerous methods are developed and tried to increase reliability and decrease the number of failures. The most common methods in use today for analysing failures are fault tree analysis (FTA) [3], [13] and failure mode and effects analysis (FMEA) [4], [16].

The FTA (Fault Tree Analysis) method [9] is a kind of analysis used in safety and reliability engineering to understand how systems can break down. It is "*graphic model of the various parallel and sequential combinations of faults that will result in the occurrence of the predefined undesired event*" [17]. "*The main purpose of FTA studies is to develop comprehensive technology for early fault detection, system life prediction and enhanced maintenance intervals*" [8]. The method is often used as a tool for qualitative and quantitative analysis [18], [11] of the failure probabilities of components. Andrews and Fecarotti in the description of their research declared that "*the performance of engineering safety systems is governed by both its initial design and also the maintenance strategy employed once it is in operation*" [2]. FTA is a top-down approach analyzing all events starting from "*the system failure or accident which is called the TOP event of the fault tree"* [12]. The system then continues with the following events at levels below the top one. FTA is created using two gate logics, 'AND' or 'OR', depending on the determination of the causes of failure of an event. FTA analysis helps in understanding possible drawbacks in the machinery design, but has one deficiency, it cannot be applied to dynamic events [1]. Despite that fact, the FTA technique can and should be applied in connection with the creation of the maintenance plan.

According to the presented claims, it can be assumed that FTA can be the answer to the question, it can be the replacement source for CPMS. To recheck those claims an investigation is conducted and presented in this paper. The data on the FTA of the turbocharger, which was published by the same group of authors, is compared with actual manufacturers recommendations [10] forming the conclusion if FTA can serve as an optional source for the construction of the PMS.

2. FAULTS DETECTED BY FTA

Knežević et al [8] analyzed Marine Diesel Engine Turbocharger System and simulated faults during the research. According to the presented FTA (Figure 1), the undesired event is Turbocharger failure. Main defects of the turbocharger can be attributed to the failure of the turbocharger, either on the air or exhaust side or on the air cooler failure.

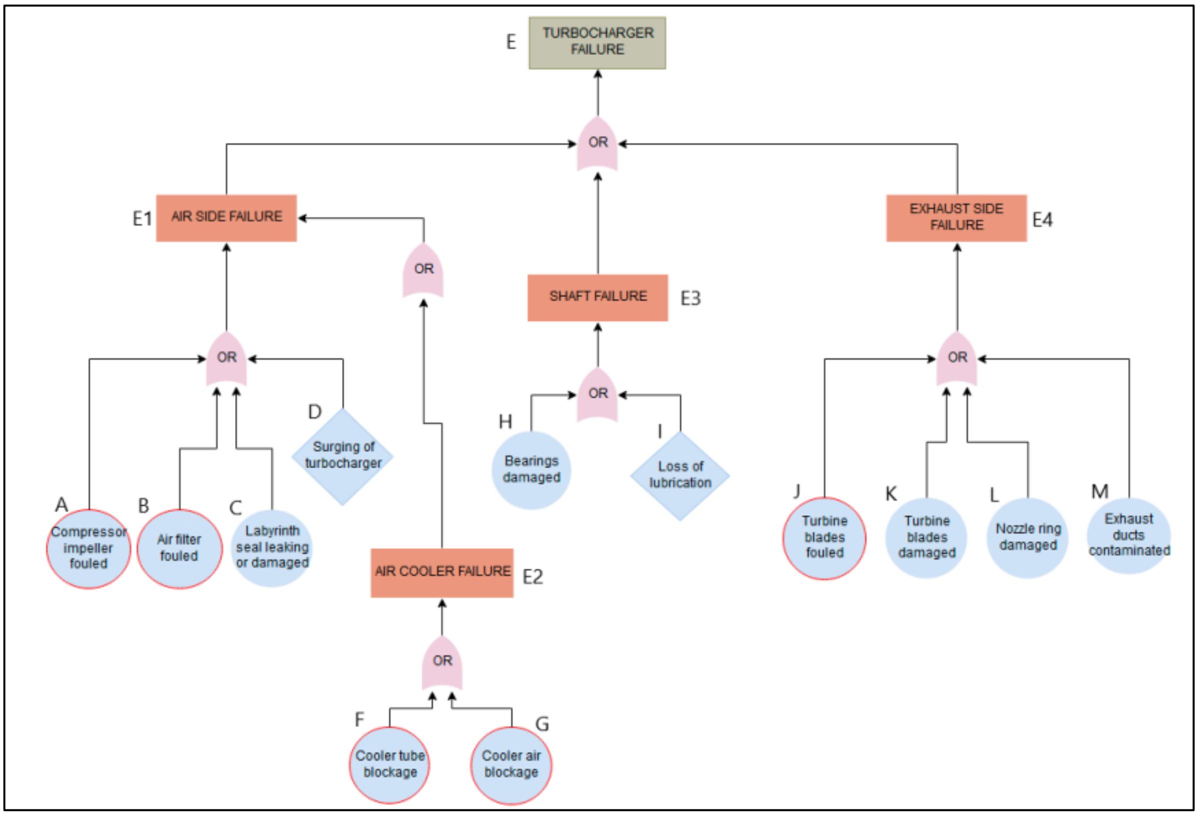


Figure 1 The fault tree of the turbocharger system

Source: Knežević et al [8]

The undesired event can be caused by several causes and reasons [8]:

- On the Turbocharger air side:
  - Turbocharger compressor impeller fouled (Item 1),
  - Turbocharger air filter fouled (Item 2),
  - Turbocharger labyrinth seal leaking or damaged (Item 3),
  - Turbocharger surging (Item 4),
- On the Turbocharger shaft:
  - Turbocharger bearings damaged (Item 5),
  - Turbocharger bearings loss of lubrication (Item 6),
- On the Turbocharger exhaust side:
  - Turbine blades fouled (Item 7),
  - Turbine blades damaged (Item 8),
  - Turbine nozzle ring damaged (Item 9),
  - Turbine exhaust ducts contaminated (Item 10),
- On the air cooler:
  - Cooler tube blockage (Item 11),
  - Cooler air blockage (Item 12).

FTA method listed these 12 Items (numbered from 1 to 12) as a potential source of malfunctions or faults of the turbocharger. If the assumption that FTA can be a replacement source for the CPMS database development, all those items should be found in the manufacturer's manuals.

2.1. Maintenance list derived from FTA

FTA analysis of the Marine Diesel Engine Turbocharger System produced the list of twelve possible causes for the undesired event. Based on the professional experience of the authors of the article following maintenance can be derived from the list:

- Turbocharger overhaul and parts replacement (It will eliminate items 1, 3, 5, 7, 8, 9 and10),
- Compressor cleaning in operation (It will prevent 1),
- Turbine cleaning in operation (It will prevent 7 and 10),
- LO filter cleaning (It will prevent 6),
- Air cooler cleaning (It will prevent 11 and 12),
- Turbine filter cleaning (It will prevent 2).

The remaining Item 4 can be caused by various reasons; above mentioned maintenance will eliminate that defect.

3. MANUFACTURER'S MANUALS

Table 1 presents the manufacturer's fault-finding chart [10] where all faults are listed with the possible cause of the deficiency paired with the indication of the malfunction.

Table 1 Turbocharger fault finding chart

Cause and corrective action no.	Operation Malfunctions → / Possible Causes ↓	Exhaust gas temperature in front of turbine too high	Charge air pressure too low	Charge air pressure too high	Speed too high	Speed too low	LO Pressure too low	LO loss	Hesitating start, short run-down time	Unusual strong noise	Turbocharger vibrates	Compressor surges	*FTA item no.*
1	Air filter mat or silencer fouled	O	O		O								2,
2	Compressor fouled	O	O		O				O				1,
3	Turbine wheel heavily fouled	O	O		O				O		O	O	4, 7,
4	Turbine nozzle ring lightly fouled			O		O							7,
5	Turbine nozzle ring heavily fouled/ restricted	O	O		O				O			O	4, 9,
6	Retaining, thrust or counter-thrust ring damaged								O	O	O		8,
7	Piston seal ring defective							O					
8	Seals damaged, connections untight							O					3,
9	Defective bearings, imbalance of rotor		O		O				O	O	O		5,
10	Rotor rubbing	O	O		O				O	O	O		5,
11	Foreign objects in front of/in compr. and/or turbine	O	O		O				O	O	O	O	4,
12	Turbine wheel or compressor wheel damaged	O	O		O				O	O	O		8,
13	Oil coke behind turbine wheel								O				10,
14	Heavy erosion on turbine wheel/turbine nozzle ring	O	O		O								8, 9,
15	High air-intake temperature	O	O		O								1
16	Low air-intake temperature			O		O						O	2, 12
17	Charge-air cooler fouled	O	O		O							O	11,12
18	Charge-air pipes leaks	O	O		O								11, 12,
19	Charge-air temperature too high	O										O	1, 4
20	LO inlet temperature too high						O						11
21	LO pressure too high							O					6,
22	LO filter dirty						O						6,
23	LO manometer defective						O						6,
24	Overpressure in oil drain or crankcase							O					
25	Inlet/exhaust valves, valve slots of engine fouled	O	O		O							O	4, 10
26	Exhaust gas pipe leaks	O	O		O								
27	Exhaust-gas back-pressure behind turbine too high	O	O		O							O	4, 10,
28	Fuel injection at engine faulty	O	O		O							O	4,

Source: MAN Diesel SE [10]

A column is added on the right side of the Table 1. The column is giving a cross reference from Table 1 to the list of the faults described by FTA. All items from the FTA list can be discovered here, as well as some additional entries. According to the manufacturer's manual [10], all above listed malfunctions and causes are addressed in the recommended maintenance which is presented in Table 2.

Table 2 Manufacturers' recommended turbocharger maintenance schedule

Description of the maintenance work	Operating hours				
	24	150	250	3000	24000 to 30000
Check Turbocharger for unusual noise	O				
Check turbocharger and system pipes for leakage	O				
Check all fixing screws, casing screws and pipe connections for tight fit				O	
Clean the turbine (dry cleaning)	1				
Clean the turbine (wet cleaning)		1			
Clean the compressor (in operation)		1			
Clean the air filter			1		
Major overhaul					O

O – Maintenance work
1 – As required, depending on the condition

Source: MAN Diesel SE [10]

All items from FTA analysis are addressed in this maintenance schedule except items regarding Air cooler, LO filter and manometer. Important items like LO filters are today addressed by the alarm system (diff. pressure sensor), the air cooler is made by another manufacturer and the maintenance is addressed in another instruction manual [5], while defective manometer should be spotted in regular check of the duty Engineer.

3.1. Maintenance plan in the CPMS

The maintenance plan in the CPMS (Figures 2 and 3) is obviously created using the data supplied by the Turbocharger [5] and Air Cooler Manufacturers [10]. The maintenance plan in the CPMS fully corresponds to the Manufacturers' recommended turbocharger maintenance schedule, with Class Survey included as well as LO filter cleaning.

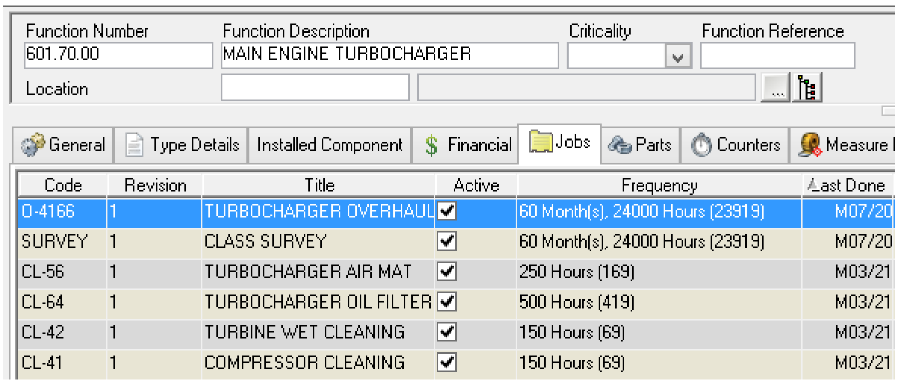


Figure 2 Turbocharger Maintenance plan

Source: confidential

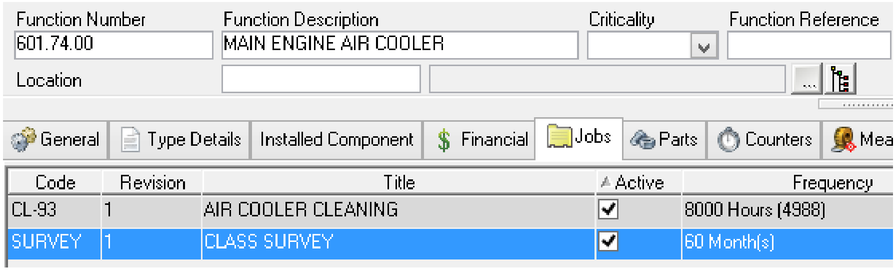


Figure 3 Air Cooler Maintenance plan

Source: confidential

4. CONCLUSION

The maintenance list derived from FTA together with the experience produced the list which is very similar to the list provided by the equipment manufacturer and the list in the CPMS. Another part of the maintenance plan is scheduling of works. Actual scheduling as per maintenance list derived from FTA is not presented, authors had different opinions about scheduling of some works (different experience). Even with differences in scheduling, the maintenance plan based on the FTA closely resembles the actual maintenance plan, recommended by the Manufacturer.

As it is shown, Fault Tree Analysis together with Engineering experience can provide enough information to create well designed maintenance plan which will be very similar to the maintenance plan recommended by the Manufacturer. Therefore, FTA can and should be recommended to all persons involved into CPMS database creation as a replacement source of information when equipment manuals are missing. The drawbacks are that the solution requires an Engineer well versed in the FTA method as well as equipment maintenance principles and that Engineers can perform scheduling differently.

REFERENCES

[1] Adedigba, S. A.: Dynamic risk assessment of process operations, Doctoral dissertation, Memorial University of Newfoundland, St Johns, Canada, 2017.
[2] Andrews, J.; Fecarotti, C. System design and maintenance modelling for safety in extended life operation. Reliability Engineering & System Safety- 2017. Vol. 163, pp. 95–108. DOI: 10.1016/j.ress.2017.01.024
[3] Asuelimen, G.; Blanco-Davis, E.; Wang, J.; Yang, Z. and Matellini, D.B.: Formal Safety Assessment of a Marine Seismic Survey Vessel Operation, Incorporating Risk Matrix and Fault Tree Analysis, Journal of Marine Science and Application, Vol. 19(2), pp. 155-72, 2020, DOI: 10.1007/s11804-020-00136-4
[4] Cristea, G. and Constantinescu, D.M.: A comparative critical study between FMEA and FTA risk analysis methods. In IOP Conference Series: Materials Science and Engineering, 2017, Vol. 252, No.1, pp. 012046.
[5] DongHwa Entec: Air Cooler LKMY-C2-1887 Instruction Manual, 2014, Busan, South Korea.
[6] Gašpar, G.; Poljak, I.; Orović, J.: Computerized Planned Maintenance System Software Models, Pomorstvo, 2018, Vol. 32(1), pp.141-145, DOI: 10.31217/p.32.1.14
[7] IACS: A Guide to Managing Maintenance in Accordance with the Requirements of the ISM Code (IACS Rec 74), 2017, ISBN: 978-1-85609-752-9
[8] Knežević V.; Orović J.; Stazić L.; Čulin J. Fault Tree Analysis and Failure Diagnosis of Marine Diesel Engine Turbocharger System. Journal of Marine Science and Engineering. 2020 Dec; Vol. 8(12). Pp. 1004. DOI: 10.3390/jmse8121004
[9] Lee, W. S.; Grosh, D. L.; Tillman, F. A.; & Lie, C. H.: Fault Tree Analysis, Methods and Applications, a Review. IEEE Transactions on Reliability, 1985, Vol. R-34(3), pp. 194–203: DOI: 10.1109/tr.1985.5222114
[10] MAN Diesel SE: TCR 22–2 – C1Operating Instructions, Augsburg, Germany, 2007,
[11] Melani, A. H. A.; Murad, C. A.; Caminada Netto, A.; Souza, G. F. M. de and Nabeta, S. I.: Criticality-based maintenance of a coal-fired power plant. Energy, 2018. Vol. 147, pp. 767–781. DOI: 10.1016/j.energy.2018.01.048
[12] Rausand, M. and Hoyland, A.: System Reliability Theory: Models and Statistical Methods, John Wiley & Sons, Hoboken, New Jersey, 2009, ISBN: 0470317744

[13] Relkar, A.S.: Risk Analysis of Equipment Failure through Failure Mode and Effect Analysis and Fault Tree Analysis. J Fail. Anal. and Preven. 2021. DOI: 10.1007/s11668-021-01117-7
[14] Stazić. L.; Komar, I. and Račić, N.: Evaluation Methodology for Ship's Planned Maintenance System Database, Transactions on maritime science,2017, Vol. 21;6(02), pp.109-16.
[15] Teng, S.: and Ho, S.: Failure mode and effects analysis, International Journal of Quality & Reliability Management, Vol. 13(5), pp. 8–26, 1996, DOI: 10.1108/02656719610118151
[16] Vesely, W.; Goldberg, F.; Roberts, N.; Haasl, D. Fault Tree Handbook; NUREG-0492; Nuclear Regulatory Commission: Rockville, MD, USA, 1981
[17] Volkanovski, A.; Čepin, M.; Mavko, B. (2009). Application of the fault tree analysis for assessment of power system reliability. Reliability Engineering & System Safety, 2009. Vol. 94(6), pp. 1116–1127. DOI: 10.1016/j.ress.2009.01.004

MODELING AND SIMULATION OF INNOVATIVE AUTONOMOUS UNDERWATER VEHICLE PAST

Piotr Szymak
Polish Naval Academy
Gdynia, Poland
E-mail: p.szymak@amw.gdynia.pl

Paweł Piskur
Polish Naval Academy
Gdynia, Poland
E-mail: p.piskur@amw.gdynia.pl

Piotr Piątek
CBR B4
Rzeszów, Poland
Email: p@2pp.pl

Jan Muchowski
CBR B4
Rzeszów, Poland
Email: jmuchowski@b4.org.pl

Szymon Trawiński
CBR B4
Rzeszów, Poland
Email: strawinski@b4.org.pl

UDK 629.56(204.1)
544.272

Summary

Recently, the increasing development of Autonomous Underwater Vehicles (AUVs) can be seen in the world. Different constructions of AUVs for various applications may be observed. The paper is devoted to the innovative AUV called PAST being developed and built within the Polish development project entitled "Development of the underwater autonomous transport system" (no. POIR.01.01.01-00-0893/20). Particularly, the paper focuses on modelling and simulation of the AUV to verify the PAST concept before its implementation. At the beginning of the article, an introduction to the research is inserted. Then, the mathematical model of the AUV and, consequently, the identification of the model parameters using Computational Fluid Dynamics (CFD) are presented. Next, the results of numerical research carried out in the Matlab environment are presented. In the end, the conclusions for future research are formulated.

Keywords: modelling and simulation, computational fluid dynamics, autonomous underwater vehicle

1. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) are robots that can perform many different underwater missions, both civilian and military. Civilian usage of AUV is mainly connected with various inspections of the aquatic environment, especially for oceanography and marine biology purposes [2][3]. Considering military applications of AUV, the following missions should be mentioned: mine countermeasure, anti-submarine warfare, and Intelligence, Surveillance, and Reconnaissance (ISR). The innovative underwater autonomous vehicle PAST is destined to transport different payloads from starting to target waypoints.

According to the desired purposes of project no. POIR.01.01.01-00-0893/20, called PAST project, underwater autonomous transport system PAST will be an underwater unmanned electric vehicle type AUV. PAST's essential function will be the transport of various types of cargo. The underwater autonomous transport system will be equipped with wireless communication and control systems. It will be capable of independent (autonomous) motion to the user-programmed location on the surface or underwater and detection and avoidance of obstacles on its route. The expected product will be recognized as an innovation on an international scale.

The offshore wind energy market and the offshore mining installations market will be the most crucial target group for the project results. PAST will enable faster, safer, and cheaper execution of works and inspections of underwater offshore facilities: drilling platforms, underwater installations, dams, locks, bridges, docks. The underwater autonomous transport system will be used to construct and inspect offshore wind farms, underwater ICT networks, and pipelines. In addition, it is required to deliver various types of tools, equipment, and a supply of air cylinders for divers during underwater works.

In Figure 1 initial 3D project of PAST is illustrated. The vehicle consists of a transport compartment in the middle with two cylindrical containers with batteries and power electronics ended with the screw propellers. Such construction can be easily changed with the larger or smaller source of electric energy and/or propeller producing the larger or smaller thrust. Moreover, three maneuver thrusters are attached to the transport compartment. The microprocessor and sensor systems are located in the bow part of the middle compartment, while the stern part of this compartment is destined for holding the transported load. To counteract different buoyancy of different shipments, the additional ballast tank is predicted.

The PAST is planned to be an autonomous vehicle capable of moving across the desired trajectory with obstacle detection and avoidance, which demands the implementation of precise underwater navigation and autonomy algorithms [5][6]. Moreover, the autonomous operation needs additional operations, e.g., data processing from different sensors, e.g., for obstacle detection [9].

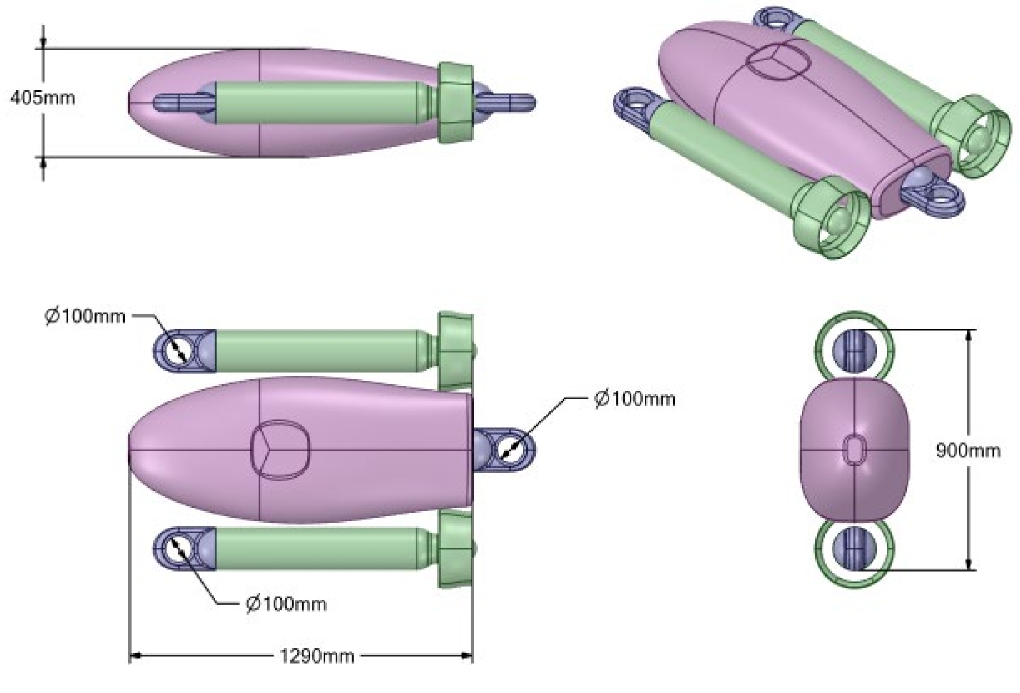


Figure 1 3D project of underwater autonomous transport system PAST

Source: project no. POIR.01.01.01-00-0893/20

In the next section, the mathematical model is described [1]. Then, the identification of the model parameters using analytical [4][7] and CFD approaches is considered. Next, the results of numerical research of the PAST are presented and discussed. In the end, the conclusions and the bibliography are inserted.

2. MATHEMATICAL MODEL OF AUV

Usually, an underwater vehicle is considered as a rigid body with the following features [1]:

- it has three planes of symmetry,
- it moves in six degrees of freedom,
- it moves at a low speed in a viscous fluid.

The vehicle's motion is described using two reference systems: (1) the movable coordinate system associated with the vehicle $x_o y_o z_o$ and (2) the immovable coordinate system associated with the Earth xyz.

The origin of the movable coordinate system O responds to the center of gravity of the vehicle. At the same time, its axes are defined as: (1) x_o is a longitudinal axis directed from the stern to the bow, (2) y_o is a transverse axis directed to the starboard, and (3) z_o is a perpendicular axis directed from top to bottom. Changes in the position of the movable coordinate system $x_o y_o z_o$ are described for coordinate system xyz associated with the Earth. Because the vehicle moves at a relatively low speed, the acceleration of points on the Earth's surface is ignored, and the coordinate system xyz is considered stationary. Therefore, the centrifugal and centripetal forces and moments of force caused by the Earth's spin may be neglected.

Considering the above assumptions, to simulate the motion of AUV, a nonlinear model of an underwater vehicle in 6 degrees of freedom [1] was used. The movement of the vehicle is described by six differential equations, very often presented in the compact matrix form:

$$\mathrm{M}\dot{\nu} + \mathrm{D}(\nu)\nu + \mathrm{g}(\eta) = \tau \tag{1}$$

here:

ν – vector of linear and angular velocities in the movable system,

η – vector of vehicle position coordinates and its Euler angles in the immovable system,

M – matrix of inertia (the sum of the matrices of the rigid body and the added masses),

$\mathrm{D}(\nu)$ – hydrodynamic damping matrix,

$\mathrm{g}(\eta)$ – vector of restoring forces and moments of forces of (gravity and buoyancy),

τ – vector of control signals (the sum of the vector of forces and moments of force generated by propulsion system τ_p and by environmental disturbances τ_d).

The assumptions presented earlier in this section cause simplification of the matrices shown in equation (1) to the main diagonal. It helps in receiving the final values of the matrix elements, which are presented in detail in the next section.

The left side of the equation (1) includes forces and moments of force caused by the following physical phenomena: the vehicle's body's inertia and the added masses of a viscous liquid, hydrodynamic dumping water environment, a balance of gravity and buoyancy. In contrast, the right side of equation (1) represents the vector of forces and moments of force acting on the vehicle generated by a propulsion system and additional environmental disturbances (under the water's surface, especially a sea current). The parameters of the matrices included in the left side of equation (1) were determined using Computational Fluid Dynamics (CFD) simulation research and dependencies included in [1][2]. All the details are included in the next section. The vector of forces and moments of force τ_p generated by the propulsion system consists of the following elements:

$$\tau_p = [X, Y, Z, K, M, N] \tag{2}$$

here:

X, *Y*, *Z* – the forces acting respectively in longitudinal, transverse, and vertical axes of symmetry,

K, *M*, *N* – the moments of force acting relative to respectively longitudinal, transverse, and vertical axes of symmetry

The calculation of the vector of force and moments of force generated by propulsion should consider the specific configuration of the propulsion system [4]. In Fig. 1, the 3D design of AUV PAST with the propellers is illustrated. As it can be seen, the vehicle is driven by two main thrusters mounted on its stern (acting in the horizontal plane) and three maneuver thruster: one of them installed on the stern and two other mounted in the bow part of the vehicle (acting in the vertical plane).

Two main thrusters produce thrust in the longitudinal axis of symmetry which is responsible for the advance velocity of the vehicle. Moreover, the difference in generated thrusts produces a moment of force relative to the vertical axis of symmetry, changing the PAST course. Because of locating the main thrusters in an extreme position, it is expected to receive good maneuverability on the horizontal surface.

Three maneuver thrusters acting in the vertical surface enable us to generate thrust in the vertical axis of symmetry, i.e., submerging and emerging vertically. Moreover, the difference in generated thrusts allows inducing moments of force relative to the longitudinal and lateral axes of symmetry, i.e., to change respectively roll and trim of the PAST. The most important seems to be trim change which enables to control depth.

3. IDENTIFICATION OF MODEL PARAMETERS

3.1. Introduction to numerical calculations

CFD calculations were performed to identify the PAST parameters. Those parameters will be used in the mathematical model of PAST motion. The calculations were divided into three stages to reduce the time of the analysis.

- Stage 1: Calculating the thruster's characteristics (ducted propeller with pre-swirl stator).
- Stage 2: Determination of the hull hydrodynamic characteristics without taking into account the working propellers.
- Stage 3: Calculation of the added mass for the hull movement in the X, Y, and Z axes.

Split analysis of the thruster and hull characteristics is possible due to the small influence of the working thrusters (propeller) on the hydrodynamic characteristics of the hull.

Due to the short duration of the project, the CFD results presented in the article are only a part of the necessary CFD calculations to perform the model of PAST motion.

The calculations were performed using the CFD Ansys Fluent package. It is used for numerical calculations of fluid dynamics using the finite volume method. In most of the estimates presented in the article, the flow is modeled using the RANS equations (Reynolds averaged Navier-Stokes). URANS (Unsteady Reynolds averaged Navier-Stokes) equations were used only to calculate the value of the added mass. The authors focused on the presentation of the calculation results without specifying a set of equations and describing the RANS and URANS methods. A description of the RANS and URANS methods can be found in each CFD manual, *i.a.* [11]

3.2. Determination of the main thruster characteristics

The article presents research on main thrusters. Maneuver thrusters will be tested and developed in further stages of the project. To develop the PAST motion model, the authors will use the assumed/known characteristics of maneuver thrusters .

In the preliminary stage of the project, the thruster characteristics were calculated using the previously developed geometry of the thrusters used in the previous project. These thrusters are designed to work with a 2kW engine with a nominal speed of 1800 RPM. Next, the dedicated PAST thruster will be developed based on the presented calculations.

The concept of PAST control in translational motion assumes the use of rudders installed at the outlet of the nozzles of main thrusters. Therefore, calculations were also made of the influence of the rudder deflection located in the propeller stream on the forces and moments generated by the rudder.

The calculations were performed for different rudder deflection angles and different pitching and yawing angles. The results of these analyzes are not included in this article.

In Figure 2, the 3D project of the thruster is illustrated. The geometrical model of the thruster has been simplified for numerical calculations. The model's simplification consisted of a significant reduction in the length of the battery compartment, which is to be ultimately integrated within one unit with the thruster. The research team's experience shows that the shortening of the shape of the cylindrical part in front of the thruster for the calculation conditions presented in the article (Reynolds and Froude numbers) has little effect on the characteristics of the thruster. However, it allows for a significant reduction of the grid mesh. The thruster consists of a three-blade ducted propeller with a D = 248mm diameter with pre-swirl stators. The pre-swirl stators are both: a structural element that fixes the duct to the engine and an element that increases the thruster's efficiency [15]. The use of a pre-swirl stator also positively influences the operation of the rudder behind the duct, making the velocity field in front of the rudder more uniform.

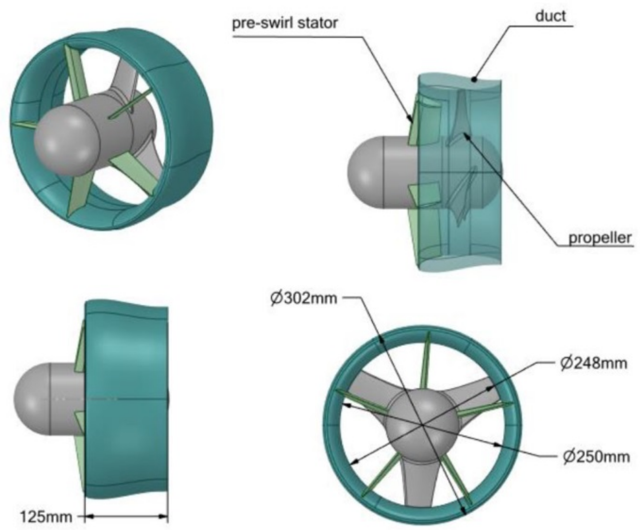


Figure 1 View and dimensions of the main thruster

Source: project no. POIR.01.01.01-00-0893/20

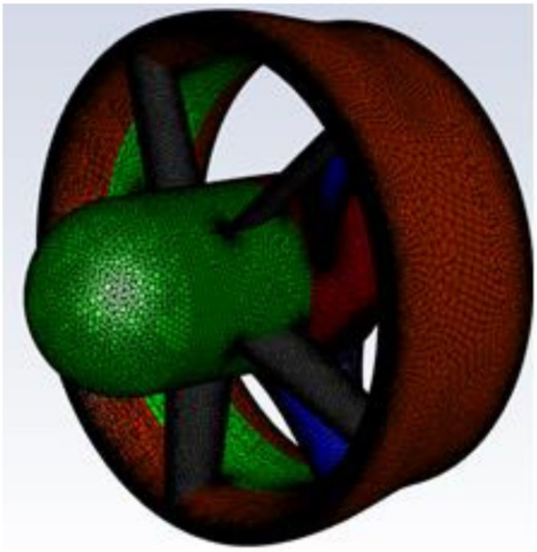


Figure 3 Mesh geometry of thruster surface

Source: project no. POIR.01.01.01-00-0893/20

In the calculations of the thrusters, a cylindrical domain with the diameter 5D and length 20D was used. The finite volume mesh was discretized with polyhedral elements. The grid had 6 million elements. Inflation layer modeled with 15 prism elements. The height of the first element of the inflation layer was Y+ ~ 30. In Figure 3, the mesh geometry of the thruster is illustrated.

The calculations were performed as steady flow using the MRF (Multiple Reference Frame) method [11] and k-ω SST turbulence model. The velocity inlet condition was used at the inlet to the domain and cylindrical walls, at the outlet: pressure outlet. Flow model: incompressible, single phase. Fluid model: water-liquid. Physical properties of the fluid density ρ = 998 [kg/m^3], temperature T = 298 [K]. For simplicity, the same reference pressure in the entire domain was assumed, equal to the atmospheric pressure P = 101325 [Pa]. It is the least favorable case in terms of cavitation. In Figure 4, boundary conditions and the size of the domain are illustrated.

The hydrodynamic characteristics of the thruster were calculated for the inflow velocity V from 0 to 4.2 m/s and nominal rotational speed of 1525 RPM. Assuming propeller diameter $D = 0.248\ [m]$, the advance coefficients were in the range J=<0-0.66>. The values of the forces and moments generated by the thruster are presented in the form of dimensionless coefficients [12]:

$$J = \frac{V}{n*D} \quad 3)$$

$$K_T = \frac{T}{\rho*n^2*D^4} \quad 4)$$

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

$$\eta = \frac{K_T}{K_Q} * \frac{J}{2\pi} \quad 6)$$

$$P = \frac{RPM*Q}{9.55} \quad 7)$$

Here:
T - Propulsion thrust[N]
n - propeller rotational speed [1/s]
RPM – propeller rotational speed [1/min]
D - propeller diameter [m]
Q – propeller torque (X axis)
V – velocity inlet

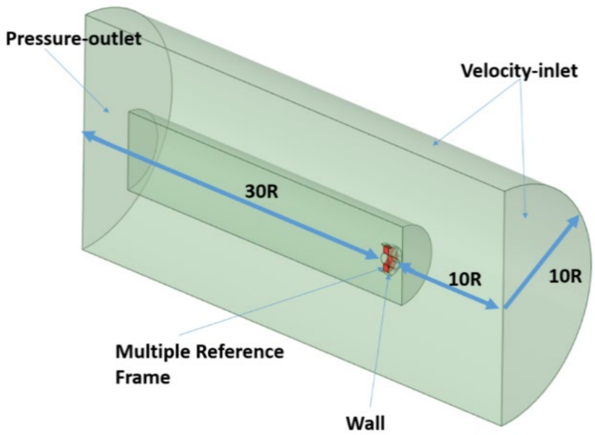


Figure 4 Size of the domain and boundary condition. Inner cylinder was used as a region to refine the grid

Source: project no. POIR.01.01.01-00-0893/20

The results of the numerical calculations are presented in Table 1. The characteristics of the thrust coefficient, the torque coefficient, and the efficiency depending on the advance coefficient for different configurations are shown in Figure 5.

Table 1 Coefficient calculated for the thruster

$J[-]$	$K_T[-]$	$K_Q[-]$	$\eta\ [-]$
0	0,2703	0,0202	0
0,1	0,2385	0,0197	0,1928
0,2	0,1973	0,0189	0,3317
0,3	0,1574	0,0180	0,4182
0,4	0,1167	0,0156	0,4752

0,5	0,0755	0,0134	0,4485
0,6	0,0325	0,0105	0,2954
0,63	0,0187	0,0093	0,2009
0,66	0,0053	0,0082	0,0679

Source: project no. POIR.01.01.01-00-0893/20

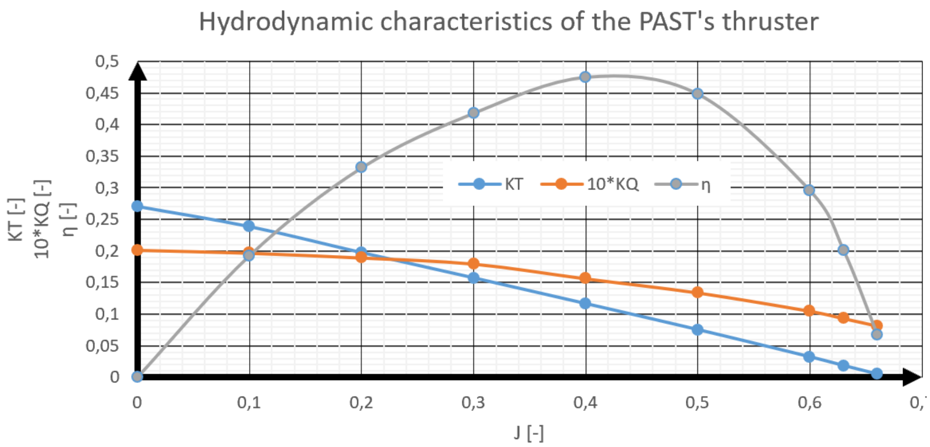


Figure 5 Hydrodynamic characteristics of the PAST's thruster

Source: project no. POIR.01.01.01-00-0893/20

The research team has repeatedly validated the presented methodology of CFD testing of thruster by comparing CFD calculations with the experimental results. The difference of the coefficients' values between the calculations and the experiment did not exceed 5%-even in static thrust testing.

3.3. Calculation of the hull characteristics

The research aimed to determine the hydrodynamic characteristics of the PAST hull using the CFD [14].

Calculations of the hull hydrodynamic characteristics were divided into two cases:

- Hydrodynamic characteristics (forces and moments coefficient) depends on pitch angle and the yaw angle for motion along the X axis, and forces and moments coefficient for motion along Y and Z axes
- Added mass calculation in case of the surge, sway, heave motion.

3.3.1. Hydrodynamic characteristics

The geometric model of the analyzed hull-thrusters assembly consists of: the transport compartment, two cylindrical containers with nozzles of main thrusters and with the front caps/nozzles of maneuver thrusters arranged symmetrically to the XY PAST plane, and the caps/nozzles of maneuver thrusters in the rear part of the transport compartment. The geometric model was simplified by removing the hull to main thruster joints, antennas, sensors, periscope, and mountings. The model does not consider the modeling of the propellers of the primary and maneuver thrusters and the pre-swirl stator of the main thrusters. Hull components and dimensions are shown in Figure 6.

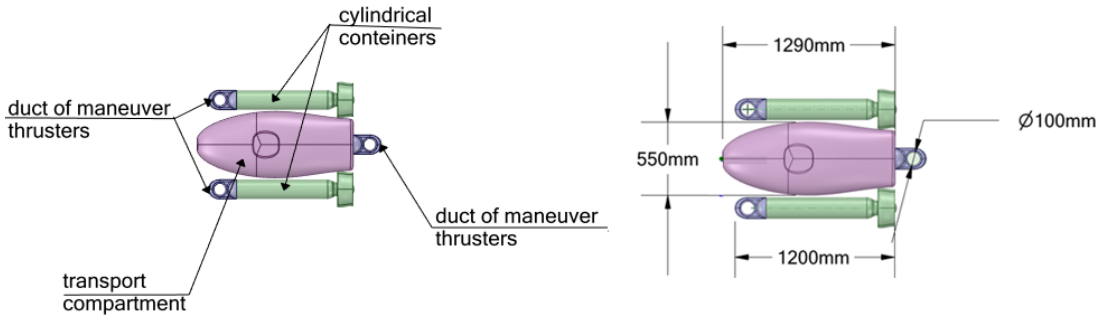


Figure 6 Hull component names and dimensions

Source: project no. POIR.01.01.01-00-0893/20

The scope of the calculation on the hydrodynamic characteristics of the PAST hull is presented in Table 2.

For the tests described in Table 2, the flow was modeled as a steady flow. The k-ω SST turbulence model was used for calculations. The polyhedral mesh consisted of about 6 million cells. Inflation layer modeled with 15 prism elements. The height of the first element of the inflation layer was Y+ ~ 1. Because the analyzed object is symmetrical, the calculations were made for half of the model, using the symmetry type of the boundary condition. Example domain and boundary condition in case 2 from the table are presented in Figure 8. For other variants from Table 2, the orientation of PAST into the domain was adjusted. The hydrodynamic characteristics of the PAST hull were determined for speed described in subsection 3.2.

Table 2 Calculation cases for hull hydrodynamic characteristic

CASE	PITCH ANGLE θ [DEG]	YAW ANGLE ψ [DEG]	VELOCITY DIRECTION	VELOCITY [m/s]
1	0	0	x_0	3
2	4	0	x_0	3
3	8	0	x_0	3
4	0	4	y_0	3
5	0	8	y_0	3
6	0	0	z_0	0.5
7	0	0	y_0	0.5

Source: project no. POIR.01.01.01-00-0893/20

The reference system related to the vehicle and the ground shown in Figure 7 was adopted in the CFD calculation.

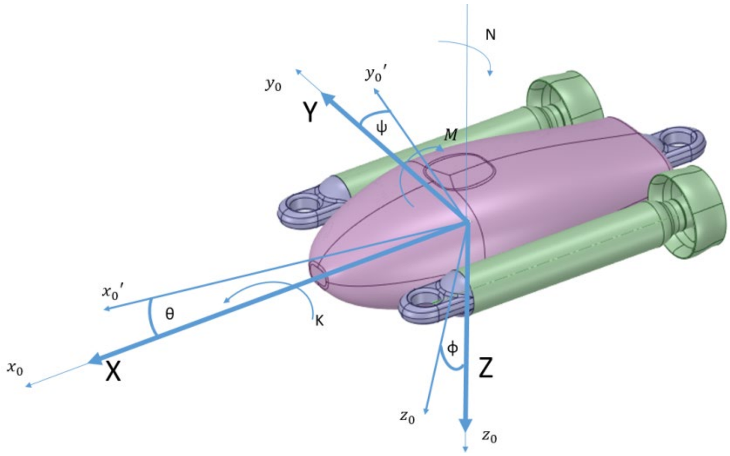


Figure 7 Reference system associated with the PAST

Source: project no. POIR.01.01.01-00-0893/20

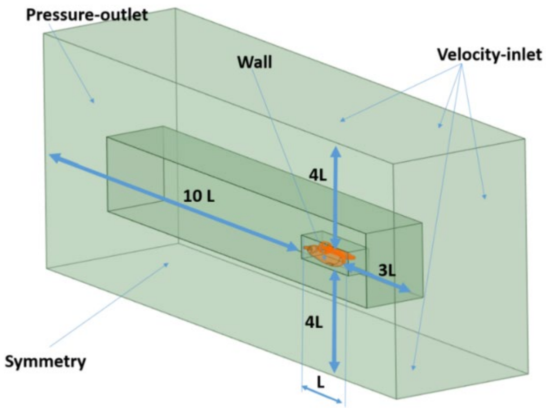


Figure 8 Size of the domain and boundary conditions. Inner cuboids were used as a region to refine the grid

Source: project no. POIR.01.01.01-00-0893/20

The results are presented in the form of dimensionless coefficients of forces and moments defined in the following way [12]:

$$C_X = \frac{F_X}{0,5*\rho*v^2*S} \quad 8)$$

$$C_Y = \frac{F_Y}{0,5*\rho*v^2*S} \quad 9)$$

$$C_Z = \frac{F_Z}{0,5*\rho*v^2*S} \quad 10)$$

$$C_M = \frac{M}{0,5*\rho*v^2*S*l} \quad 11)$$

$$C_N = \frac{N}{0,5*\rho*v^2*S*l} \quad 12)$$

$$C_K = \frac{K}{0,5*\rho*v^2*S*l} \quad 13)$$

Here:

F_x – surge force

F_y – sway force

F_z – heave force

S – unit reference area (1 [m^2])

l – unit reference length (1 [m])

The results of the numerical calculations are presented in Table 3. The sign convention of the adopted coordinate system is shown in Figure 7. Therefore, some of the coefficients have a negative sign. Figure 9 shows the C_x coefficients. Moreover, the pressure distribution on the hull is presented in Figure 10.

Table 3 Hydrodynamic coefficients for different cases of the PAST calculations

CASE	C_{Xa}	C_{Ya}	C_{Za}	C_M	C_N	C_K
1	-0.0263	-----------	0.00015	-0.00057	-----------	-----------
2	-0.034	-----------	0.0753	-0.00327	-----------	-----------
3	-0.0432	-----------	0.1567	-0.00405	-----------	-----------
4	-0.0299	-0.0200	-0.00172	0.00035	4.09441E-05	-----------
5	-0.0279	-0.0391	-0.0062	-0.00103	-0.000393	-----------
6	0.0827	-----------	0.7324	0.11945	-----------	-0.0979
7	0.0378	-0.126	-----------	-----------	0.024656	-0.0263

Source: project no. POIR.01.01.01-00-0893/20

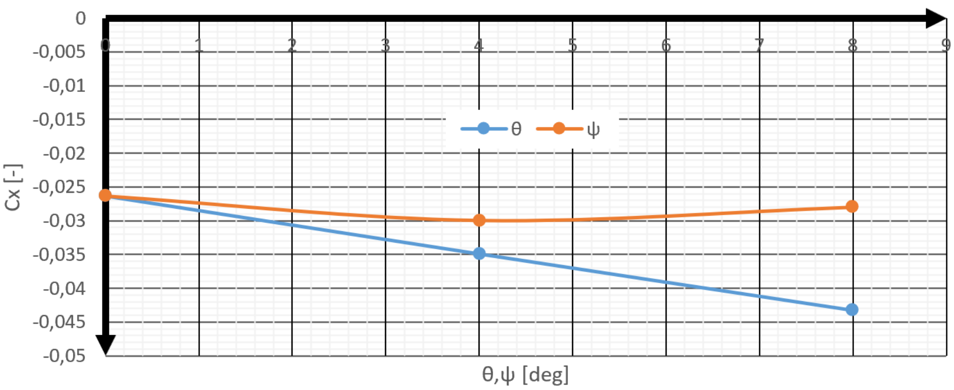


Figure 9 Characteristic of $\mathbf{C_X}$ C coefficients

Source: project no. POIR.01.01.01-00-0893/20

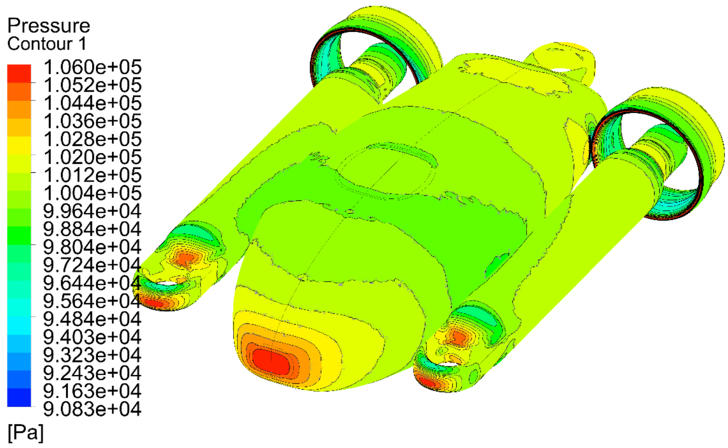


Figure 10 Pressure distribution on the hull

Source: project no. POIR.01.01.01-00-0893/20

3.3.2. Added mass calculation

The next step in the calculations for the PAST hull was the determination of PAST added masses for the main directions of inflow (x, y, z).

To calculate the added masses, it is necessary to calculate accelerations in selected directions of movement. For this purpose, speed profiles were defined for each calculation case (Table 4). In the applied calculation methodology [13], the PAST geometric model remains stationary, but the value of the inflow velocity at the domain entrance changes. Therefore, the flow was modeled as unsteady. The time step was 0.005s, which corresponds to the Courant number ~ 1. Other boundary conditions, models, fluid properties, and mesh used were identical to the calculations described in subsection 3.2.

To calculate each case, the following method depending on the change of velocity in time was used. Figure 11 shows the velocity profile at the inlet for motion along X axis (case 1), Y and Z axis (respectivle case 2 and case 3).

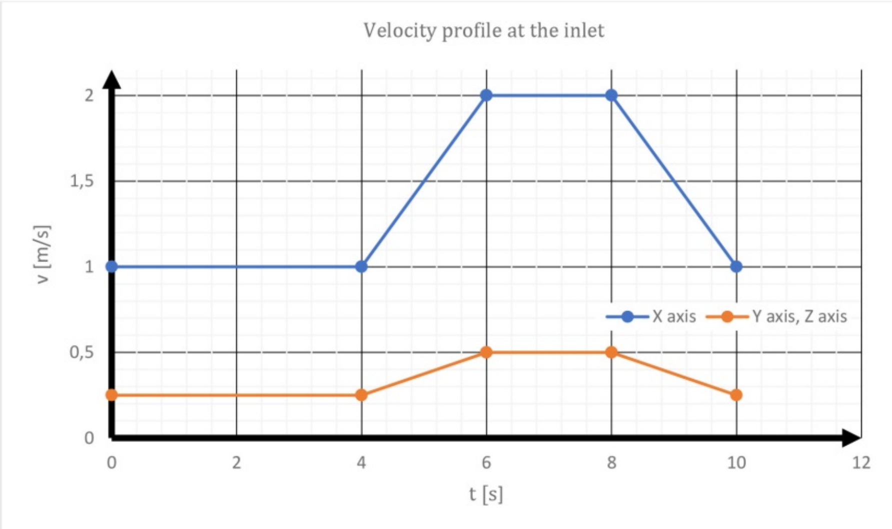


Figure 11 Velocity profile at the inlet for different cases

Source: project no. POIR.01.01.01-00-0893/20

The results are presented in the form of added masses expressed in [kg].

The added mass can be defined as [13]:

$$m_a = \frac{|F_{t=t_3} - F_{t=t_0}|}{|a|} - m_w \qquad 14)$$

Here:

m_a – the added mass [kg]

$F_{t=t_3}$ – the force in time moment t_3 [N]

$F_{t=t_0}$ – the force in time moment t_0 [N]

m_w – the mass of the displaced volume of fluid [kg]

a – the acceleration [m/s^2]

The obtained results of the numerical calculations are presented in Table 4.

Table 4 Added mass results for different cases

CASE	$m_a[kg]$
1	37.32
2	88.41
3	267.73

Source: project no. POIR.01.01.01-00-0893/20

4. RESULTS OF NUMERICAL RESEARCH

An obtained mathematical model with tunned parameters using CFD calculations allows us to make the first tests. The tests were divided into two main groups:

1. The speed test,
2. The maneuver tests in the horizontal and vertical planes.

The speed test was made in a quite simple way. In the first second of the simulation, the vehicle was driven with the maximal force in the longitudinal axis of symmetry. Then, in the 15th second, the vehicle was stopped by decreasing the force in the longitudinal axis of symmetry to zero (Figure 12).

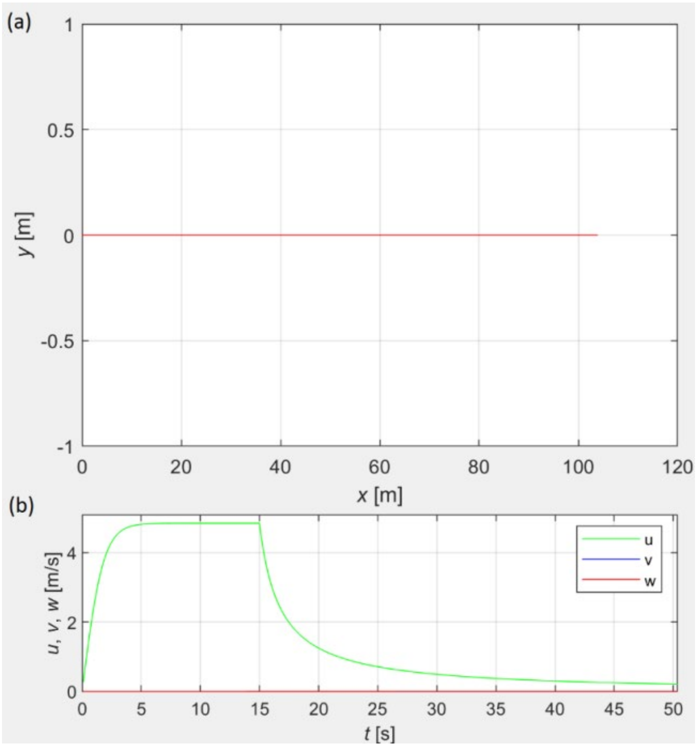


Figure 12 Trajectory (a) and velocity (b) changes in time during the speed test

Source: project no. POIR.01.01.01-00-0893/20

As we can see, the PAST achieved maximal velocity equal to 4.84 m/s after approx. 5 s, and it decreases this velocity to 10% of its maximal value after the following 15 s.

The next maneuver test in the horizontal plane (Figure 13) depends on the change of course angle equal to 540° with a constant advance velocity equal to 1 m/s. The results of this test are visualized in Figure 13. The diameter of the circulation is approx. 4 m. Using two main thrusters mounted on two boards of the vehicle enables to make the change of course almost in place. It was also proved using the designed simulational model.

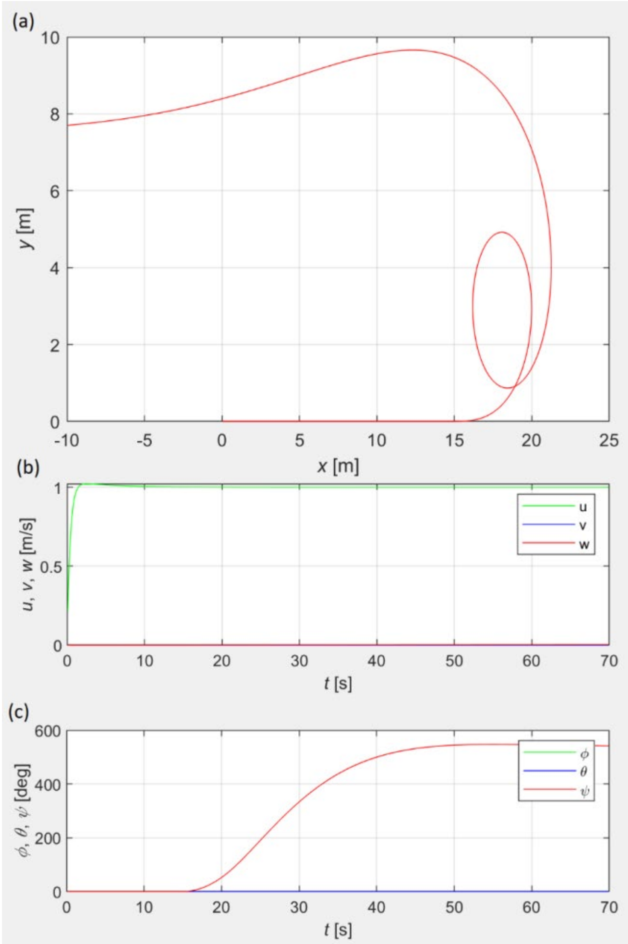


Figure 13 Trajectory (a), advance velocity (b), and course (c) changes in time during maneuver test in the horizontal plane

Source: project no. POIR.01.01.01-00-0893/20

The last test was carried out to verify maneuverability in the vertical plane (Figure 14). The moment of force relative to the latitudinal axis of symmetry equal to 1 Nm drove the PAST in the first second of simulation and −1Nm in the 10th seconds of simulation.

As it can be seen, such forcing signal causes submerging to the depth above 3 m and then emerging. During the motion, the vehicle changes its depth with a constant rate of 1 m per 10 seconds. The moment of force relative to the latitudinal axis of symmetry may be increased. Still, the more enormous value will cause the larger change of the trim angle, which can not be suitable for the vehicle stability.

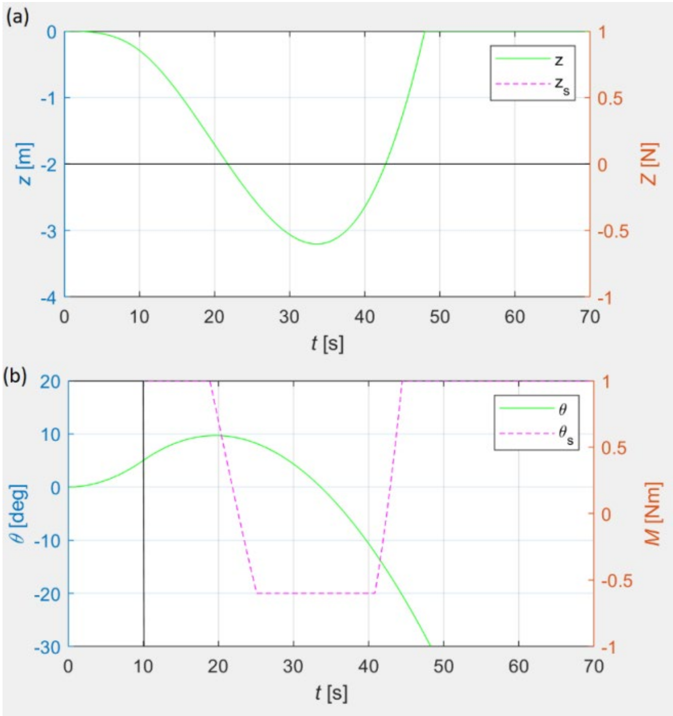


Figure 14 Depth (a) and trim angle (b) changes in time during maneuver test in the vertical plane

Source: project no. POIR.01.01.01-00-0893/20

5. CONCLUSIONS

Designed mathematical model of the motion of underwater vehicle PAST allows us to make initial tests of the vehicle manoeuvrability and possibly low-level control. Using a CFD environment allows obtaining precise values of the model parameters in a wide range of simulated fluid conditions. After possible construction improvements, those parameters can be easily tuned employing CFD calculations.

During the following research, the controllers of the main parameters of PAST motion will be designed and tuned. To obtain optimal settings of the controllers, different methods can be used. For example, the previous research received promising results for controllers of the biomimetic underwater vehicle using the Particle Swarm Operation (PSO) method [10].

Acknowledgment

The research results presented in the paper were achieved within the project entitled "Development of the underwater autonomous transport system" (no. POIR.01.01.01-00-0893/20), co-financed by the Polish National Centre of Research and Development.

REFERENCES

[1] Fossen, T.: "Handbook of Marine Craft Hydrodynamics and Motion Control", Wiley, 2011.

[2] Kondeti, L.: “Review of Autonomous Underwater Vehicles” in “Autonomus Vehicles”, Intech, 2018, doi: 10.5772 /intechopen.81217

[3] Ozgur, Y., Bulent, O., Yilmaz, A.: A review on motion control of the Underwater Vehicles, ELECO 2009 - 6th International Conference on Electrical and Electronics Engineering.

[4] Prakash Panda, J., Mitra, A., Warrior, H.: A review on the hydrodynamic characteristics of autonomous underwater vehicles, Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 2020, Volume: 235 issue: pp. 15-29, doi: 10.1177/1475090220936896

[5] Praczyk, T., Szymak, P., Naus, K., Pietrukaniec, L., Hożyń, S.: Report on research with biomimetic autonomous underwater vehicle - low level control, Scientific Journal of Polish Naval Academy, 2018, R. 59, no 1(212), pp. 105-123.

[6] Praczyk, T., Szymak, P., Naus, K., Pietrukaniec, L., Hożyń, S.: Report on research with biomimetic autonomous underwater vehicle - navigation and autonomous operation, Scientific Journal of Polish Naval Academy, 2018. R. 59, no 2(213), pp. 53-67.

[7] Prestero, T.; Verification of a Six-Degree of Freedom Simulation Model for the REMUS Autonomous Underwater Vehicle, Ph.D. thesis, 2001.

[8] Sandeep, J., Mahender, S.: "A Review Paper on: Autonomous Underwater Vehicle", International Journal of Scientific and Engineering Research, 2015, Vol. 6, pp. 38-40.

[9] Szymak P., Praczyk T., Naus K., Malec M., Morawski M.: Research on biomimetic underwater vehicles for underwater ISR, Proc. of SPIE 9831, Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR VII, 2016, DOI:10.1117/12.2225587.

[10] Szymak, P., Piskur, P.: Using Particle Swarm Optimization for Tuning Course Controller of Biomimetic Underwater Vehicle, Book of Proceedings: 8th International Maritime Science Conference / ed. Špiro Ivoševic, Pero Vidan, Kotor: University of Montenegro; University of Split, 2019, pp. 255-262.

[11] ANSYS Fluent Theory Guide 2019R1

[12] Carlton, J.: "Marine propellers and propulsion", Elsevier, 2007.

[13] Javanmard, E., Mansoorzadeh, S., Mehr, J.A.: A new CFD method for determination of translational added mass coefficients of an underwater vehicle, Ocean Engineering 215 (2020) 107857

[14] Sadeghozadeh, M.R., Saranjam, B., Kamali, R.: Optimization of a Diver Propulsion Vehicle Hydrodynamics Parameter and its' Shape Improvement by CFD Method for Improving Underwater Speed Record, Journal of Applied Fluid Mechanics, Vol.10, No.5 pp.1319-1328, 2017

[15] Koushan, K., Krasilnikov, V., Nataletti, M., Sileo, L., Spence, S.: Experimental and Numerical Study of Pre-Swirl Stators PSS, Journal of Marine Science and Engineering, 2020,8,47

DEVELOPMENT OF CROATIAN LEGAL FRAMEWORK FOR LIABILITY FOR DEATH AND PERSONAL INJURY OF SEAFARERS

Igor Vio
University of Rijeka Faculty of Maritime Studies
Rijeka, Croatia
E-mail: ivio@pfri.hr

UDK 347.79: 349.2
347.79:347.447

Summary

The paper presents the development of the Croatian national legislation regulating civil liability for damages caused by personal injury, health impairment and loss of life of seafarers. The first part commences with the historical background of this particular field of maritime law, which dates back to maritime customs of ancient Middle Eastern and Mediterranean cultures, including Athens and Rome, continues with legal regimes developed in the middle ages in the form of Lex Maritima, and provides an overview of the significant contribution of the statutes of the medieval towns on the Croatian coast of the Adriatic, emphasizing the elaborate rules of the Statute of Dubrovnik. This development continued in the period of formation of national states in Europe, and paper focuses on national maritime legislation of those states that had the most important influence as they used to regulate maritime industry in Croatia in times before it gained independence. The final part elaborates the development of the relevant legal regime in the Croatian Maritime Codes of 1994 and 2004, including the outline of its latest amendments and of potential future advancements.

Keywords: personal injury and death of seafarers, shipowner's liability for crewmembers' damages for health impairment

1. INTRODUCTION

The profession of a seafarer, due to the very nature of the job, has always been a source of various dangers, so it is the same today, with the application of contemporary technology on ships. Technological advances have reached unprecedented proportions, and the requirements for the training of ships for safe navigation, training of seafarers, and the provision of protective equipment at work, are becoming increasingly stringent almost every day. Rights and obligations, which are divided between the shipowner and crew members, are directed towards a common goal - ensuring conditions for safe navigation, and for safe living and working conditions on board [21, p. 92]. The crew members of seagoing vessels as employees require and have special protection provided by regulations in the field of labour and social law. Their employment is characterized by two elements related to the ship's crew and the ship itself, namely the protection of crew members as employees and the safety of navigation, because the special regime of life in the shipping community must be consistent with the goals and purpose of navigation. These factors require the regulation of the employment of a member of the ship's crew as general and special regulations of labour law, as well as special regulations of maritime law.

On the other hand, the shipowner, as a natural or legal person who, as the owner of the ship, is the organizer and holder of the navigation venture, is also the holder of liability for all contractual and non-contractual obligations, and is liable for damages due to bodily injury or death of crew members. Conditions that may cause damages can easily occur, and this raises questions about the basis of liability for damage, its extent and amount, and how to repair it. Every damage, as well as that in the physical sphere of seafarers, raises the question of liability for damage, its amount and the repair of damage. Based on the individual shares of shipowners and crew members in terms of acting or failing to act in order to enable safe navigation and life at sea, the share of responsibility of each of them in any damage to the ship is estimated.

The national regulations to be applied to these cases include not only labour law, but also the provisions of maritime law, company law, and procedural law governing temporary suspension and enforcement on board. All of the above has been further complicated over the last decades as a result of the introduction of flags of convenience that allow unscrupulous shipowners to circumvent their obligations to crew members. The relentless conditions of the international market in the shipping industry often impose maintenance on shipowners precisely by maintaining low standards on ships in their merchant fleet, not only in terms of maritime safety and marine protection requirements, but also in terms of crew salaries as well as the poor conditions of their life and work on board.

It is the duty of the shipowner to keep constantly maintained the conditions for safe operation on board [21, p. 75]. If any omission in this regard on or near the ship results in injury to any of the crew members, passengers or shore-based staff, the shipowner shall be liable for damages. In certain cases, the liability of the shipowner extends to injuries suffered by crew members during their stay on land. According to court rulings in some countries, such as the United States, compensation for personal injuries is extremely high. Therefore, in addition to the primary duty of the shipowner and the master of the ship to apply consistently all prescribed safety measures on board to act preventively in terms of protection of the highest values, namely life, health and integrity of all persons on board, there is a duty of the master to take care of various economic aspects. Namely, in order to reduce the risk of the shipowner being liable for compensation for personal injuries of seafarers, the master must be constantly vigilant regarding any malfunctions on board that could affect the safety of work. He should also make sure that the causes and circumstances of any accident that leads to an injury, even the smallest one, are conscientiously recorded.

2. HISTORICAL DEVELOPMENT

2.1. Old Age and Early Middle Ages

Maritime industry, as an economic activity, has most often been specially regulated since the earliest periods, and the parts of the regulations governing maritime trade also applied to seafarers. The beginnings of maritime law are associated with the customs of ancient Middle Eastern and Mediterranean cultures (Babylon, Chaldea, Egypt and Phoenicia) [13, p. 30]. Thus, the Code of Hammurabi, as the oldest codification of Babylonian law, four millennia ago already contained regulations governing the basic rights of the ship, the status of shipowners, the employment of the crew, determining the amount of freight for sea transport and shipbuilding [7, p. 8]. There is a lack of written traces of ancient maritime law in the literature, despite the staggering level of maritime development (first among the Phoenicians, later in the Greek city-states, especially in Athens), so that there is a common standpoint that maritime law of that ancient time was regulated by customs because maritime navigation could not develop without any regulations [9, p. 7].

An important collection of such ancient rules of maritime law is the so-called Maritime Code of Rhodes (*Nomos Rodion Nautikos*). These are rules of customary law that most probably date back to the time of ancient Greece, and which were codified only in the Byzantine period, most likely in the 8th century. This Code is comprehensive as it covers all aspects of the exploitation of merchant ships, and Chapters V and VII regulate in particular the rights and obligations of seafarers, including the liability of shipowners for personal injury and death of crew members. As for the Roman law, which emerged as the starting point of the European continental legal system, mention should be made of the praetor's edict, which was in force throughout the Roman Empire as *jus gentium*, meaning that it applied to all inhabitants, including Roman citizens and members of other nations. One part of this regulation also applied to seafarers (*nautae*). It is also worth mentioning Digeste, the legal collection of Emperor Justinian from 533 AD, which mentioned the ancient Greek regulations on the general average (*Lex Rhodia de iactu*) [7, p. 8].

After the disintegration of the Roman Empire, there was a particularization of legal regulations, so that there were several legal sources that regulated maritime law, and the first such recorded source are the so-called Rules of Oleron, which emerged as a compilation of maritime customary law in Northern Europe. The exact date of their creation is impossible to determine, but the oldest existing manuscripts date from the early 14th century, while most theorists dealing with legal history hold that they were created much earlier, perhaps as early as the first half of the 12th century [6, p. 114]. It should be noted that the Oleron Rules were not decrees or laws in today's sense, as a regulation adopted or adopted by a state legislative body, but consisted of legal principles and individual legal judgments that were collected to show how decisions were delivered in individual cases by a court having jurisdiction over maritime disputes in the city of Oleron in France. As for the mentioned legal principles, they originated from Italian sources that are definitely based on the tradition of Roman law, but adapted to local customs and thus became the basis of maritime law in the states on coasts of the North Sea and the Atlantic Ocean. The Oleron Rules also formed the basis for other medieval collections of maritime regulations such as the Visby Rules (named after a small town on the island of Gotland) and the laws of the Hanseatic League, a trade confederation that connected over fifty cities from London west to Novgorod in Russia. Finally, the Oleron Rules also became the foundation of English maritime law as they were incorporated into a collection of regulations known as the Black Book of the Admiralty. It is interesting that all these sources contain similar provisions on the right of a sick or injured crew member to maintenance and care.

On the other hand, in the Mediterranean area, the basic principles and rules of the Rhodes Maritime Code continued to live on in regulations such as the Maritime Consulate (*Consulatus maris*), which originated in Spain and is a valuable source of legal rules for seafarers. It also contained norms that gave legal protection to seafarers in terms of their salaries, so they had a kind of early form of a maritime lien if their income could not be settled from the value of cargo or freight.

2.2. Medieval Statutes of Croatian Coastal Towns

In the same period of the Middle Ages, numerous statutes of towns at the eastern Adriatic coast were adopted, which authors usually divide into two maritime circles: the northern, which was influenced by the Venetian *Statuta navium* from 1255, which includes the statutes of Rab (1330), Krk (1512), Pag (1433), Zadar (1305), Šibenik (15th century), Skradin (13th century) and Split (13th century), while the so-called southern group was influenced by the Dubrovnik Statute of 1272, which includes the statutes of numerous cities including Hvar (1331), Korčula (1216/1428), Mljet (1310), Lastovo (16th century) and Kotor (14th century) [8, p. 65]. Of course, in all these statutes, the influence of Byzantine law is noticeable through the previously mentioned *Nomos Rodion Nautikos*. The Statute of Split had most of rules of the maritime law in its Book VI, which contained eleven rules on seafarers [14, p. 243]. The Statute of Rab, which consists of five books, can be used to illustrate the maritime regulations of the northern Adriatic circle, and the regulations of maritime law are contained in the third and fourth book. Thus, in Book III, in Chapter 24, there is a provision on the contract between a seafarer and the "master" of a ship: "Furthermore, we order that any contract concluded by seafarers with the master or masters of the ship, either with a down payment or on faith, be firm, withdraw from the contract or that the master or masters may release seafarers under penalty of as many coins as they had contracted, except for a justifiable reason for illness, and unless the contractors agree that the contract should not be maintained" [1, p. 131]. The authors note similarities with the Zadar Statute, which provides for two exceptions in which the shipowner does not have to pay to the seafarer the agreed amount of salary: the first is an agreement and the second is illness [1, p. 132]. Some authors have interpreted this second exception as a situation where a sick seafarer cannot perform his part of the obligation, while others held that it was in fact the dismissal of a seafarer taken in exchange for a sick seafarer, and in the event of the latter's recovery he would be dismissed without the right to the payment of a contractual salary [12, p. 259].

Interestingly, this Rab Statute does not mention the duration of the contract unlike other sources that differentiate seafarers who were engaged for a single voyage or for a specific period, usually one year.

The Dubrovnik Statute names seafarers engaged on a particular voyage *marinarii ad viagium*, who of course receive a salary for their work. Unlike them, the specificity of Dubrovnik was the existence of the so-called *marinarii ad partem*, who instead of a salary, receive from the shipowner a share in the profits from the maritime venture, but also bear their costs. In addition, *marinarii ad partem* and their families had better legal position in cases of death, injury or illness compared to *marinarii ad viagium* [16, p. 316].

Another specificity in Dubrovnik was the existence of the so-called *marinarii in entega*, which was in fact a special legal relation that creates an entrepreneurial community between shipowners, seafarers and merchants who would enter into a maritime - commercial venture together [16, p. 317].

The Statute of Rab contains two regulations that consider the responsibility of seafarers. The first regulation is in Book III in Chapter 22. "On seafarers who leave the ship and work against the master", and it speaks of a situation when a seafarer or seafarers do not want to fulfil the contract until the expiration of the time for which it was concluded, and will as punishment have to return double the amount of salary to the shipowner, and the authorities on Rab can punish them additionally. It is stated that this is analogous to the regulation from Chapter 39 of the Venetian Statutes of Tiepolo [1, p. 134]. The second provision on the liability of seafarers from Book III of Chapter 23 of the Rab Statute regulates the case when seafarers leave the ship temporarily without authorization, i.e. without the permission of the shipowner or the master of the ship. It is interesting to note that unlike the position of seafarers, the Statute does not regulate the position or obligations of shipowners, so it is assumed that this issue was regulated by local customs or under the influence of Venetian regulations as in some other statutes.

The Dubrovnik Statute contains the regulations of maritime law in its Book VII [17, p. 19]. The Statute was created at a time of strong social and economic development of Dubrovnik out of the need to scatter the previous laws according to various records, which sometimes contradicted each other, and also regulated too many superfluous things, while others were incomplete, unclear or complicated. The codifier himself commented in the introduction that this sometimes caused misunderstandings and disagreements even among the judges themselves, all of which resulted in the need to create one refined harmonized and unified code. The authors note that in Book VII, which regulates maritime law, the maritime destiny of Dubrovnik was determined as early as the 13th century. However, it should be borne in mind that this Statute, although one of the oldest sources of maritime law, already at the time of its creation, actually codified maritime customs that reflected the centuries-old maritime tradition.

The proof for this may be found in the texts written by Constantin Porfirogenet, the Byzantine historian from the 10th century, who recorded the fact that as early as 869, Dubrovnik ships transported Croatian troops to the other side of the Adriatic in Bar, where these soldiers took part in battles against the Arabs. The seventh book of the Dubrovnik Statute also contains several provisions that are interesting for the topic of this paper, so Article XXII stipulates that a seafarer whose contract expires before the end of the voyage will be obliged to complete the voyage if requested by the shipowner in proportion to the contracted salary. Article XXIII stipulates that in the event of the illness of a seafarer, who sails for a share of the profits, which occurred before the departure of the ship from Dubrovnik, the shipowner shall have no obligations to him. On the other hand, if a seafarer falls ill after the ship has sailed from Dubrovnik and has to be disembarked elsewhere, his share of the profits flows during the entire voyage as if he were present on the ship, and he will also receive a fixed amount for expenses like other seafarers. In the event that the ship returns to the place where the sick seafarer was left for treatment and finds him healthy, the seafarer may re-board the ship. According to Article XXIV, if a seafarer sailed for a salary according to the contract and fell ill already in Dubrovnik, he would have to return the received amount to the shipowner or his deputy, and the latter would no longer have any obligations towards him. However, if the ship sailed from Dubrovnik and the seafarer fell ill and remained in another place, he was entitled to a part of the salary in proportion to the period of service on the ship. Finally, Article XXV stipulates that in the event of the death of a seafarer who sailed for a salary that occurs before the expiry of the contract, a proportionate share of the salary belong to his family, while after the death of a seafarer who sailed the share of the family's profits for that one trip. It is understandable that Dubrovnik's maritime law was not petrified by the provisions of the cited Book VII of the Statute, but continued to develop depending on political, social and economic circumstances, and later regulations such as the Navy Regulations (*Ordo marinaritiae*) of 1511 and 1535 should certainly be noted. The Ordinance on Marine Insurance (*Ordo super assecuratoribus*) of 1568 and the Regulations on National Navigation of the Republic of Dubrovnik (*Regolamenti della Repubblica di Ragusa*) as a collection of regulations from the period from 1745 to 1793, which were printed in Dubrovnik in 1794 [16, p. 321].

2.3. National Maritime Legislation from 17th to 20th Century

With the emergence of national states in Europe, the aforementioned sources of maritime law became the basis for the comprehensive legal regulations governing maritime and commercial law. Thus in France a special commission appointed by Admiral Colbert drafted the Ordinance on the Merchant Navy (*Ordonnance de la Marine Marchande*) of 1681, which became a model for the drafting of laws by both French and other European states and influenced world maritime affairs [15, p. 11]. These were, first of all, Napoleon's *Code de Commerce*, and the German Commercial Code of 1861, which, in addition to the aforementioned French Decree, takes over many rules from Hanseatic law.

The Austrian monarchy did not codify maritime property law, but it is worth mentioning the Political Edict of Navigation of 1774, which regulated the matter of administrative maritime law. As for the maritime property law on our coast, it can be said that the above statutes of our cities were fully applied until the introduction of the French *Code de commerce* on the Croatian Adriatic coast (Decree on the Illyrian Provinces 15 April 1811, entering into force on 1 January 1812). However, in the parts of our country that were already included in Napoleon 's empire, after the fall of the Venetian Republic (Dalmatia), the *Code de commerce* was valid since 1808.

After the World War One and the dissolution of Austro-Hungarian Monarchy the Kingdom of Yugoslavia was created and during the two decades of its existence, there were several decrees, but work on comprehensive maritime legislation was never completed, while the Federal People's Republic of Yugoslavia (FPRY – federal state created after the World War Two) enacted several laws that partially regulated various matters of maritime law (including the FPRY Merchant Marine Crew Act). The work on maritime codification was finally realized during the Socialist Federal Republic of Yugoslavia (SFRY) with the adoption of the Maritime and Inland Navigation Act in 1977.

2.4. Maritime and Inland Navigation Act, 1977

The liability of shipowner for damage due to personal injury or death of a crew member was regulated by Article 127 of the Maritime and Inland Navigation Act (MINA).[1] Pursuant to the provisions of paragraph 1 of that Article, the shipowner was liable for damage due to personal injury or death of a crew member according to the principle of proven fault. An exception to this rule was provided in cases where personal injury or death would occur directly or indirectly due to shipwreck, collision, stranding, explosion, fire or defect of the ship, when the shipowner would be liable according to the principle of presumed fault. The liability of shipowners in this way was equal to the liability for death and personal injury of passengers, but it became the subject of sharp criticism because it had been shown that in this way seafarers were put in a disadvantage compared to employees in other industries. Namely, Article 154 of the Civil Obligations Act

[1] The Maritime and Inland Navigation Act was passed on 15 March1977, and had been in force since 1 January 1978. (Official Gazette of the SFRY No. 13/1982, 30/1985, 80/1989 and 28/1990). It was adopted as a law of the Republic of Croatia by the Law on the Adoption of Federal Laws in the Fields of Maritime and Inland Navigation, which are applied in the Republic of Croatia as national laws, Official Gazette No. 53/1991. It ceased to be valid with the entry into force of the Maritime Code on 22 March 1994.

(COA) provided for the criterion of presumed fault as a rule for the employer's liability for damage suffered by workers at work or in connection with work.

Another major complaint, apart from the mentioned inequality of seafarers with workers in other sectors of economy, was the difficult position of ship's crew members who had to prove the fault of the shipowner in damages proceedings, and this situation was especially evident in the cases of death of a crew member, when the burden of proving the negligence of the shipowner was imposed on the deceased seafarer's family. Therefore, in judicial proceedings, the courts competent for maritime disputes, taking into account the provisions of the legislative acts of the SFRY (Labour Relations Act, Civil Obligations Act and MINA) in practice made decisions in favour of seafarers, thus trying to equate workers on board with workers on land in damages disputes. Especially in cases of injuries caused by objects or devices that have the character of a dangerous thing or activity, the criterion of liability according to the principle of causality was applied (for example in cases of explosion of a compressed air bottle for the initial momentum of a diesel engine). This was essentially a matter of harmonizing the above provisions of MINA and COA with Article 73 of the Labour Relations Act (LRA). For these reasons, the proposals for amendments to the relevant provisions of the LRA, in addition to changing the basic principle of liability (presumed instead of proven fault), proposed to solve the problem of the liability of the shipowner or other responsible person in cases where the crew member was not employed (e.g. crew on sport sailing vessels) [18, p. 267].

Another example from the case law from the time of the SFRY should be mentioned: the first instance Court of Associated Labour of the Federal Republic of Slovenia, regarding the request of a crew member for compensation for damage suffered during work on the ship, found that the shipowner was objectively liable for the damage caused by ship crane as it posed an increased danger. The appellate court upheld this by rejecting the shipowner's appeal as unfounded, arguing that the shipowner was liable for damages according to the general principles of liability for damages, which included not only "subjective" liability (based on fault) but also "objective" strict liability. The Joint Labour Court held that the criterion of liability for death and personal injury of a crew member under Article 127 of the MINA was inapplicable because its application would unduly discriminate against a ship's crew member in relation to other workers. Some authors have noted two contentious situations here: the question of complex jurisdiction in disputes for damages due to the death or injury of a ship's crew member (court of general jurisdiction, court of associated labour or commercial court), and the question of application of general law by amending a provision of *lex specialis* [11, p. 267]. It was noticeable that the legal provisions in the field of civil obligations were deficient in terms of their uniformity and consistency, and the reason for this lied in the fact that the authors of certain norms were narrow specialists, as well as inconsistency of work of various expert commissions that were drafting legislation. This was the most likely cause of the divergent provisions of the COA and MINA.

In the area of employer's liability for damage suffered by a worker at work or in connection with work, the cited provision from Article 127 of the MINA was not in line with other legal provisions, especially those from the Associated Labour Act and the Safety at Work Act. For example, the employer was liable to the employee for damage caused to his health at work based on strict liability, which was a reflection of the proclaimed care of the worker and was present both in legal theory and in numerous judgments of associated labour courts. In this sense, the provision of the MINA, which introduced the principle of proven fault of shipowners for the death and injury of seafarers, and in addition to the above cases when the presumed fault was applied, put the seafarer in a very unfavourable position as a plaintiff in the proceedings.

The process regarding evidence was particularly difficult in cases of shared liability. It is possible to imagine the difficulties of the family of a seafarer who had suffered an electric shock in a ship's workshop while the ship was sailing, when they had to prove that the cause of death had been inadequate protection in the workplace and not a heart attack caused by health problems felt by the seafarer some time before the accident [11, p. 289]. Namely, the autopsy findings described in the literature in this case indicated signs that would speak in favour of an electric shock, but there were also indications of a simultaneous heart attack. Here it was really difficult to analyse the influence of several causes on the fatal consequence, that is, the percentage of causality that should be attached to each of them. Such doubts did not only occur in cases of death, but were also possible in cases of personal injuries.

An example of a seafarer in ship's engine who sustained a spinal injury while repairing an engine malfunction during navigation was described. Since the rolling and stumbling of the ship was the immediate cause of the injury, the fault of the injured party was completely excluded, but as it was obvious that the failure of the machine did not constitute a defect of the ship, the principle of proven fault should have been applied under Article 127 of MINA. However, as the injured seafarer had suffered from lumboishiatic problems for a short period before the accident, he was burdened with proving the possible contribution of the syndrome to the injury due to his possible movements in the engine room, and his position was aggravated by various opinions of eminent medical experts. It is important to note that the employer was strictly liable when the seafarer's contract of employment was terminated due to occupational or other illness, but not when the cause of the damage was personal injury, in which cases the shipowner's fault had to be proved under Article 127 of MINA.

3. DEVELOPMENT OF CROATIAN MARITIME LEGISLATION

After gaining independence, the Republic of Croatia continued to apply the Maritime and Inland Navigation Act until the adoption of the Maritime Code in 1994.[2] Due to the above criticisms, which began during the application of the MINA as a federal law of the SFRY, and continued with its adoption into the legal system of the Republic of Croatia, authors emphasized the example of the Commercial Court in Split, that held that provision of Article 127 paragraph 1 of MINA might be unconstitutional (because it violated the constitutional principle of equality of citizens before the law from Article 14 para. 2 of the Constitution of the Republic of Croatia), and asked the Supreme Court of the Republic of Croatia to initiate proceedings to review the constitutionality of this provision [5, p. 35].

The Supreme Court never initiated the procedure, reasoning that this provision is not in conflict with the Constitution of the Republic of Croatia, and with the explanation that the Constitution does not prohibit different criteria for assessing liability for damage for different legal situations, interpreting this situation so that the said provision may be equally applicable in all cases of liability of shipowners for damages due to injury or death of seafarers. In doing so, the Supreme Court expressed the view that in relation to the two legal norms, the provision of Article 154, paragraph 1 of the COA is *lex generalis*, and the provision of Article 127, paragraph 1 of the MINA is *lex specialis*.

As for the doubts with regards to the principle of presumed fault in the practice of the Supreme Court of the Republic of Croatia, the following legal views were crystallized:

I. according to the rule on presumed fault from Article 154, paragraph 1 of the COA, only the mildest degree of fault (ordinary negligence) of the liable person was presumed;
II. more serious degrees of fault (gross negligence and intent) were presumed only if such a presumption is explicitly established by a legal rule or if it follows from the meaning of the relevant legal rule;
III. outside of these cases the degree of fault was proved according to the general rules of civil procedure.

3.1. Maritime Code of 1994

The Maritime Code of the Republic of Croatia of 1994 introduced changes in the matter of liability for damage from death and personal injuries of ship's crew members, most likely based on all the above-mentioned criticisms of Article 127 of the MINA.[3] Namely, finding that there are no serious reasons for

[2] Act on the Adoption of Federal Laws in the Fields of Maritime and Inland Navigation Applicable in the Republic of Croatia as Republic Laws, Official Gazette No. 53/91.
[3] Maritime Code of the Republic of Croatia, Official Gazette no. 17/94, 74/97 and 43/96.

insisting on the criterion of proven fault, the legislator in the Maritime Code of 1994 (MC 94) in Article 161, paragraphs 1, 2 and 3, conceived the liability of the shipowner for damage from death and personal injury of the crew member arranged in accordance with the generally accepted rules on liability for damage. This article distinguishes three bases of liability: liability based on presumed fault, strict liability for damage from a dangerous thing or dangerous activity, and other cases of liability based on causality.

Thus, if we compare it with the derogated Maritime and Inland Navigation Act, which stated the principle of presumed fault only in exceptional cases, the Maritime Code of 1994 contained completely different solutions. The Maritime Code draft of 1993 provided for the strict liability of the employer as a general principle. On the other hand, for the damage suffered by a member of the ship's crew who was not employed by the shipowner, provided solutions were identical to the provisions of Articles 127, paragraphs 1 and 2 of the MINA. In the literature, we may find the view that this legal solution from the draft law was much clearer and more pragmatic than the one in the final text of the Maritime Code, but these positive legal solutions were interpreted as undoubted progress compared to the former Maritime and Inland Navigation Act [2, p. 12].

The provision in paragraph 1 of Article 161 reads: "The shipowner shall be liable for damage caused by personal injury or death to a member of the ship's crew unless he proves that the damage occurred because of his fault." Of course, this provision concealed an error pointed out at the time by many authors, who were proposing that it should be corrected by replacing the word “because” with the word “without” [5, p. 35]. Another way to correct this error would have been to formulate the provision in such a way that the shipowner was liable for the stated damage if he did not prove that the damage did not occur due to his fault. In any case, if one wished to be released from liability for damage, the shipowner had the burden of proving that the damage suffered by a crew member was due to a cause for which he was not liable.

Particular doubts were raised by Article 161, paragraph 2 of the MC 94, which provided that the shipowner would be liable for damage caused by a dangerous object or dangerous activity in accordance with the general legal regime on liability for damage from a dangerous object or dangerous activity from the Civil Obligations Act (COA 91). Pursuant to the provision of Article 154, paragraph 2 of the COA, liability for damage arising from a dangerous object or dangerous activity was present regardless of the fault, so only two presumptions of liability had to be met for shipowner's liability: damage and causation.[4] This reference to the application of the COA has motivated authors to pose justified questions about the reason for the existence of the cited provision of the Maritime Code, when the same conclusion would be reached by the subsidiary application of the COA. The most probable cause, which directly followed the cited provision of the Maritime Code, was that the ship as a whole was not in itself a dangerous thing, but that in certain circumstances it might be.

Therefore, the only thing that the injured crew member of the ship had to prove in court was the existence of the damage and the fact that it was the result of a dangerous thing or dangerous activity. Pursuant to Article 173 of the COA, causality was presumed, and this presumption could be rebutted by the shipowner only if he proved that his activity or dangerous object did not cause damage because it arose due to a completely different cause. However, the prevailing view was that the ship as a whole was not a dangerous thing, but under certain circumstances it could become so, and individual parts of the ship themselves could be a dangerous thing, too. It should be emphasized that legal norms did not define these terms, so it was left to court practice to determine the danger of activities or things in each individual case. The relevant legal theory mentioned the generally accepted position of case law according to which a movable or immovable thing whose position, use, property or even existence posed a certain danger to the environment would be considered dangerous, so that thing should be monitored and used with special care [10, p. 84].

[4] Civil Obligations Act, Official Gazette no. 53/91, 73/91 and 3/94.

As far as dangerous activity is concerned, we do not have such a general position defined in court practice, but one common denominator can be drawn from numerous judgments, which is that courts consider as dangerous activities those, which by their nature or given the circumstances in which they are performed, are dangerous for the environment. COA 91 in Article 177 foresaw the three possible exoneration reasons. These were: *force majeure*, defined as the action of a cause that was outside the thing, and whose action could not be foreseen, avoided or eliminated, the action of the injured party (a member of the ship's crew), and the action of a third party.

Maritime industry as a *sui generis* activity was reflected in provision of paragraph 3 of Article 161 of the MA 94, which as a second case of liability regardless of fault provided that for damage suffered by a crew member at work or in connection with work due to lack of conditions for safe work, the shipowner would be liable if he does not prove that the ship's crew member caused the damage intentionally or through gross negligence. The obligation of the shipowner to provide conditions for safe work was the reason for the introduction of this strict causal liability, where the only possibility of exculpation was to prove the qualified fault of the injured party. Due to this obligation, the shipowner was considered fully justified to bear the risk of non-existence of these conditions, even in situations when they were the result of *force majeure* or third party action, as well as in much more frequent cases of ordinary negligence of a ship's crew. The possibility of exculpation was provided for only in rare cases if the shipowner proved that the ship's crew member had caused the damage intentionally or through gross negligence.

The last provision provided for in Article 161, paragraph 4, as a matter of fact did not belong to this matter because it regulated the jurisdiction in disputes between a crew member and a shipowner, so it could be expected that it would be regulated by a special legal norm in Chapter VIII of the MC. Namely, this provision did not refer exclusively to disputes due to compensation for personal injury or death of a crew member, but regulated all disputes between crew members and shipowners, so the only reason for its inclusion in Article 161 was pragmatic need to enter it in MC 94 at the last moment before its adoption, when it was no longer possible to change the numbering of articles [2, p. 16].

3.2. Maritime Code of 2004

The shipowner's liability for damage caused by personal injury, death or new category of health impairment of a ship's crew member was not regulated by the general provisions of civil law but by the provisions of the Maritime Code of 2004 (MC 04), while the regulations of Civil Obligations Act apply in a subsidiary manner.[5]

The content of the relevant provisions of the Maritime Code (2004) reads:

a) Article 145, paragraph 1: "For damage caused by personal injury or death of a crew member or due to health impairment suffered by a crew member at work or in connection with work, the shipowner shall be liable if he does not prove that the damage was caused by his fault."

b) Article 145, paragraph 2: "The shipowner shall be liable for the damage referred to in paragraph 1 of this Article caused by a dangerous object or dangerous activity in accordance with the general regulations on liability for damage from a dangerous object or dangerous activity."

c) Article 145, paragraph 3: "For damage referred to in paragraph 1 of this Article suffered by a crew member at work or in connection with work on board due to lack of conditions for safe work, the shipowner shall be liable if he does not prove that the crew member caused damage intentionally or through gross negligence. "

d) Article 145, paragraph 4: "The shipowner, the ship operator, the ship manager, the company and the employer shall be jointly and severally liable for the damages referred to in paragraphs 1, 2, 3 of this Article."

[5] Maritime Code, Official Gazette, Nos. 181/04, 76/07, 146/08, 61/11, 56/13, 26/15, 17/19.

An analysis of these provisions leads to the conclusion that the general legal basis for liability for damage due to death, personal injury or health impairment of a crew member is liability based on the presumed fault of the shipowner (paragraph 1), while only in two cases (paragraph 2) there is his strict liability. According to the provision of paragraph 3 the shipowner is therefore responsible that there are adequate means of protection at work on his ship and that his ship is a safe place to work. This provision caused the most controversy, both in the period of several years before the adoption of the Maritime Code in 2004, and later during each amendment of the MC. As for the joint and several liability provided for in the provision of paragraph 4 of the said Article, it was a novelty in relation to the Article 161 of the Maritime Code of 1994, and represents a good solution to the issue of providing a wider circle of possible defendants in disputes for compensation of such damages.

Within the Maritime Code amendments adopted in 2013, paragraphs 2 and 3 merged into a single provision (becoming the new paragraph 2) stating: "The shipowner shall be liable for damages referred to in Paragraph 1 of this Article caused by a dangerous object or by dangerous activity, as well as for such damage suffered by the crew member at work or in connection with the work on board due to the lack of safe working conditions, according to general regulations concerning liability for damages caused by dangerous object or dangerous activity".[6]

We may well conclude that the circle of possible defendants in former paragraph 4, which became paragraph 3 since the 2013 MC amendments, was correctly prescribed, and that the introduction of the term "company" from the ISM Code is an excellent solution, but that the proposed introduction of "person who benefits from ownership" as a kind of transplant of the Anglo-Saxon legal concept of beneficial owners was not a good solution so it was right step that it was not included in this provision.

From the content of Article 145 MC 2004, it may be determined that the persons legally related to the ship, which as a rule is the place of the harmful event causing personal injury, death or health impairment of crew members, are the shipowner as the person having liability for the harmful event on one side and crew member (injured party) on the other. Their legal relationship, as well as their relationship with the ship, are a precondition for the emergence of their mutual legal obligation arising in connection with the harmful event, and at the same time they indicate their roles of plaintiff and defendant in the compensation procedure. It is not difficult to determine the person liable for damage who will be defendant in the compensation procedure, but only if the shipowner, the ship operator, the ship manager, the company and the employer are the same person. However, since in practice these are usually different persons, determining the potential defendant in these disputes is often a complex task.

The Maritime Code of 2004 kept the MC 94 solution concerning the jurisdiction, so that the courts competent for the disputes for compensation for damages suffered by crewmembers remain the commercial courts, which are authorised for all maritime proceedings [3, p. 55]. The only missing rule concerned the jurisdiction of the Croatian courts for these disputes when they had international elements, which came to focus especially after a controversial judgment of the Supreme Court initiated a turn in judicial practice. Therefore, the Act on Amendments to the Maritime Code of 2008 provides for the jurisdiction of the court of the Republic of Croatia when the plaintiff is domiciled in the Republic of Croatia, while the transitional provision of Article 47 provides for the application of this provision to all proceedings for damages a member of the ship's crew or due to a health impairment suffered by the crew member at work or in connection with work on the ship, in which no final decision has been made.[7] This provision was criticized for its inconsistence with general principles contained in EU regulations.[8]

Considering the possible future amendments to the Maritime Code of the Republic of Croatia, and due to justified concerns that seafarers and their families will find it difficult to obtain full and prompt

[6] Maritime Code Amendments, Official Gazette No. 56/2013
[7] Maritime Code Amendments, Official Gazette No. 146/2008
[8] Council Regulation (EC) No 44/2001 of 22 December 2000 on jurisdiction and the recognition and enforcement of judgements in civil and commercial matters.

compensation for damages caused by personal injury, health impairment or death, if shipowners do not have adequate insurance coverage or other financial guarantee, we consider that *de lege ferenda* (with analogy to the provision of Article 139a, which covers the repatriation costs), Croatian legislator should add the provision 139.b which would read: "The shipowner will maintain an insurance or other financial guarantee for compensation for damages caused by personal injury, health impairment or death of the ship's crew." Namely, it is necessary to promote at the national level the awareness that obtaining such effective forms of compensation is in fact merely a form of the responsibility of the shipowner to establish safe and orderly working conditions.

4. CONCLUDING REMARKS

It could be concluded that no other category of workers in modern society has legal regulations with such a significant and interesting historical background similar to seafarers. Some authors note that this tradition today can be more of a burden than an advantage [4, p. 7]. This is primarily because seafarers, compared to other professions, may have been in advantage if one looks at the aforementioned medieval sources of law, however, looking through modern standards we can say that it was indeed a matter of rudimentary rights. In the 19th and 20th centuries, when the national law governing labour relations emerged, seafarers were most often excluded from this protection because of their specific profession. This is a kind of injustice that was somewhat corrected only after. The flags of convenience syndrome emerged in the mid-20th century, which generated a deterioration in the position of seafarers and a corresponding reaction from their unions.

Unlike the ancient times when there was a single maritime law (*lex Maritima*) for maritime affairs (including status of seafarers) such as the Oleron rules and others described in the historical overview, which applied to all situations regardless of the nationality of the shipowner or seafarers and the flag state, so that in that period there were few industries in which there were such clear and uniform rules that were applicable in different situations and in different places, today the multitude of listed participants in maritime affairs with the same multitude of legal regimes lead to a complex situation in law enforcement, which can be overcome primarily through the introduction of binding international instruments, and on the other hand through unified labour law standards. It should also combine the prescribing of duties and sanctions for those who do not comply with them with various economic and other incentives for shipowners who choose to accept higher standards on their ships. This has proven to be effective in terms of the approach to tackling marine pollution from ships, so a similar dual approach can be expected to yield good results in improving the position of seafarers. With regard to the latter, it is necessary not only to provide for greater rights for seafarers in the regulations, but also to improve their real possibilities to exercise these rights. Namely, it turned out that this enabling the exercise of seafarers 'rights is in itself a significant factor in raising the general level of legal protection available to seafarers, and in many cases the adoption of measures to exercise more effectively existing rights makes it unnecessary to prescribe some additional seafarers' rights.

During the two decades of its development, Croatian maritime law has provided normative solutions that thoroughly regulated the protection of the position of seafarers, and there is no doubt that the provisions of Article 161 of the Maritime Code of 1994 represented a positive departure from the derogated Law on Maritime and Inland Navigation of 1977, introducing liability based on presumed fault instead of proven fault of the shipowner, and strict liability, which is otherwise provided by the Civil Obligations Act in cases of damage caused by a dangerous object or dangerous activity, as well as same strict liability for damage suffered by a ship's crew member at work or in connection with work on a ship due to the lack of conditions for safe work, with the intention or gross negligence of the injured seafarer as the sole reason for exoneration.

The Maritime Code of 2004 took over these quality provisions, but went even further, introducing in Article 145, paragraph 1, besides damage for death and personal injury, also damage for health impairment of a crew member, and expanding the circle of potentially liable persons in paragraph 4 of the same article.

The third significant improvement in the 2004 MC was the provision of Article 743, paragraph 2 on the possibility of a direct action against the insurer for liability for death, personal injury and health impairment of a crew member, analogous to the decision provided for mandatory liability insurance. Finally, the fourth positive step was the provision on applicable law in Article 971, which goes beyond the law of nationality of the ship and provides two more links for relations under the seafarers' employment contract: the law chosen by the parties in the employment contract and the law of closest connections.

Through the adoption of all the above legal solutions, the Maritime Code of 2004 undoubtedly improved the legal position of seafarers regarding the realization of their claims for compensation for personal injury or health impairment, as well as the position of their family members in case of their death. Croatian Maritime Code in this respect accepts modern solutions adopted in the national regulations of prominent maritime countries, and is increasingly supported by our case law, whose decisions are providing almost the same level as the decisions of courts of states with much stronger maritime and legal tradition.

Without diminishing the importance of the analysed provisions of the Maritime Code of the Republic of Croatia, which, according to the legal protection they provide to national crew members is one of the most progressive in the world if we compare them with the regulations in comparative law, taking into account the total number of Croatian seafarers involved in global shipping industry, the main conclusion is that Croatia has lost its significance as a flag state, and has become a state that supply labour force to the world merchant fleet, so that in many cases our seafarers, after maritime accidents, will not be able to take advantage of the described provisions of Croatian maritime law. Therefore, it is an important task, both for the Republic of Croatia and for the Croatian Seafarers' Union to do everything at the global level to improve the legal position of seafarers. In addition to flag states and port states, it is necessary to include associations of shipping companies, trade unions, marine insurers, financial institutions and classification societies in this global action.

REFERENCES

[1] Bartulović, Ž. (1999) Neka pitanja pomorskog prava u Rapskom statutu, Zbornik Pravnog fakulteta Sveučilišta u Rijeci, Vol. 20, No. 1., pp. 129-141.

[2] Bolanča, D. (1998) Pravni temelj odgovornosti za štetu zbog smrti i tjelesne ozljede člana posade broda s posebnim osvrtom na smisao postojanja odredaba članka 161. Pomorskog zakonika, Osiguranje, Vol. 38, No. 4-5, pp. 12-23

[3] Bolanča, D. – Amižić Jelovčić, P. (2021) Legal Sources of the Croatian Law on Liability for Damages Caused by Physical Injury, Death or Health Impairment of a Crew Member (Seaman), "Modern Challenges of Marine Navigation", Amižić Jelovčić, P. (editor), University of Split Faculty of Law, Split, pp. 47-57

[4] Fitzpatrick, D. - Anderson, M. (2005) Seafarers' Rights, Oxford University Press, London

[5] Gasparini, G. (1997) Naknada materijalne i nematerijalne štete u slučaju smrti, tjelesne ozljede i oštećenja zdravlja člana posade broda, Zbornik radova "Odgovornost brodara za smrt i tjelesnu ozljedu člana posade, osiguranje i naknada štete", Croatia osiguranje, pp. 34-39.

[6] Grabovac, I. (1991) Enciklopedija pojmova pomorskog prava, Književni krug, Split

[7] Grabovac, I. (1995) Hrvatsko pomorsko pravo i međunarodne konvencije, Književni krug, Split

[8] Hlača, V. (1991) Povijesni razvoj pomorskog prava na hrvatskoj obali Jadrana, Zbornik Pravnog fakulteta Sveučilišta u Rijeci, Vol. 20, No. 1, pp. 63-79

[9] Jakaša, B. (1983) Udžbenik plovidbenog prava, 2nd edition, Narodne novine, Zagreb

[10] Jakaša, B. (1994) Nekoliko napomena uz Pomorski zakonik, Uporedno pomorsko pravo, Vol. 36, No. 1-4, pp. 77-93

[11] Lukšić, B. (1985) Odgovornost brodara za smrt i tjelesne ozljede člana posade broda, Privreda i pravo, Vol. 24., No. 5-6, pp. 286-293

[12] Margetić, L. (1997) Srednjovjekovno hrvatsko pravo, HAZU - Adamić, Rijeka

[13] Pavić, D. (2006) Pomorsko imovinsko pravo, Književni krug, Split

[14] Pezelj, V. – Gabrić, S. (2021) Pravni položaj mornara u srednjovjekovnom Splitu, "Modern Challenges of Marine Navigation", Amižić Jelovčić, P. (editor), University of Split Faculty of Law, Split, pp. 239-261

[15] Rodiere, R. (1981) Droit Maritime, 9th edition, Dalloz, Paris

[16] Šarac, M. – Crnković, A. (2018) Radnopravni položaj članova posade (pomoraca) kroz stoljeća – jedan usporednopravni prikaz, "Modern Challenges of Marine Navigation", Amižić Jelovčić, P. (editor), University of Split Faculty of Law, Split, pp. 311-332

[17] Šundrica, Z. (1972) Prijevod sedme knjige Dubrovačkog statuta, Dubrovačko pomorsko pravo, Historijski arhiv, Dubrovnik

[18] Todorić, M. (1991) Prijedlog novele Zakona o pomorskoj i unutrašnjoj plovidbi, Uporedno pomorsko pravo, Vol. 33, No. 3-4, pp. 263-273

[19] Učur, M.Đ. (2014) Nacionalni kolektivni ugovor za hrvatske pomorce na brodovima u međunarodnoj plovidbi (2013.– 2015.). Naše more, Vol. 61, No. 5-6) - Supplement, pp. 118-125

[20] Učur, M.Đ. – Smokvina, V. (2015) Problematika radnopravnog statusa pomorca i ribara u pomorskoj plovidbi u Republici Hrvatskoj s posebnim osvrtom na registraciju ugovora o radu, Naše more, Vol. 62, No. 4, pp. 104-112

[21] Vio. I. (2020) Maritime Safety - Croatian Legal Framework. Maritime Safety in Europe – A Comparative Approach. Nawrot, J., Peplowska-Dabrowska, Z. (editors), Informa Law – Routledge. London. pp. 74-93

OVERVIEW OF THE FACTORS AFFECTING COMPLIANCE AND SAFETY OF PILOT TRANSFER ARRANGEMENTS (PTA)

Luka Vukić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: luka.vukic@pfst.hr

Zvonimir Lušić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: zvonimir.lusic@pfst.hr

Ivan Peronja
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: iperonja@pfst.hr

Danijel Pušić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: danijel.pusic@pfst.hr;

UDK 347.79:656.61

Summary

Pilot transfer arrangements (PTA) used by maritime pilots to board and disembark ships are marked as critical operations. They are regulated by an interrelated system of regulations, recommendations, industry standards, and procedures prescribed to ensure the compliance and safety of PTA utilization. The standards for pilot transfer arrangements are defined by the International Convention for the Safety of Life at Sea (SOLAS) regulation V/23, guidelines of the International Maritime Organization (IMO) Resolution A.1045(27), the International Safety Management (ISM) Code procedure and International Organization for Standardization (ISO), in particular ISO 799:2019 standard, as a non-mandatory recommendation. However, besides the strict legal background and determined set of rules, there are still deficiencies in the required procedures. It is especially visible in terms of the rigging and safe use of the ladder resulting in the violation of safety standards and possibly human health consequences. This paper aims to analyze the discrepancy between the regulations and guidelines regarding the pilot ladder safety at embarking/disembarking activities. It is performed by summarizing the critical points of the relevant documentation and indicating the principal suggestions for improvement. Following the pilots' best practice and experience, the results of the paper highlight regulatory policy ambiguous patterns that are needed to be clarified and harmonized. There is a need to eliminate non-compliant procedures and arrangements used to contribute to pilot safety as the primary obligation.

Keywords: maritime pilot, pilot transfer arrangements (PTA), pilot ladder, regulations, safety standards

1. INTRODUCTION

Maritime pilots are indispensable subjects in reaching efficiency and productivity of a port system. They act as a critical point in ensuring the safe navigation and environmental protection of a vessel in her approach to the port area [1]. As the critical navigation stage comprises the first and last leg of the voyage, in most cases these phases include the use of maritime pilots [2]. The provision of pilotage services can be considered as dualistic function, one related to securing the private interest of a shipping company in providing a special service, and other by contributing to the public interest in prevention of potential major damage and maritime accident [3]. Pilotage service relates to providing assistance to ship's master in maneuvering the ship and reaching the designated berth [4]. Due to the constant increase in volume of seaborne trade [5], there is a strong need to engage a professional representative which is familiar with local conditions when navigating into or out of the port. This includes providing safe navigation and collaboration between relevant stakeholders, as port authority, tug and mooring service, and other subjects. Maritime pilotage is usually compulsory service in majority of ports in the world [4], facilitating the transition through the safety-critical section of navigation in congested routes where high possibility of collision and grounding risks occur [6]. The constant development changes in technical and technological aspect of shipping has created the pilot service environment more demanding and complex [7]. As indicated by some studies [8], the presence of pilot on board mitigates the risk of an accident. Also, Akten [9] empirically confirmed the key function of pilotage in reducing marine accidents in constrained waters.

Extensive regulatory framework regulates the operational and organizational arrangements of piloting service mainly provided by International Maritime Organization (IMO). It focuses heavily on two important operational aspects of pilotage service, pilot transferring arrangements [10] and the safety of pilot boarding arrangements [11]. These provisions are integrated in the International Standard for Maritime Pilot Organizations [12]. Considering the significant contribution of a pilot in providing safe and efficient operation of vessel in the port area, ensuring their own safety closely relates to the vessel's safe approach to the port [13]. It is mainly reflected in the phase of boarding and disembarking of vessels at sea which is determined as a perilous activity undertaken by maritime pilots [14]. This process includes the application of pilot transferring arrangements according to the set organizational and technical requirements. The number of pilotage services has surpassed one million of operation across Europe per year [15], which potentially increases the incident rate and requires strict and clear application of regulatory procedures. Despite being studied in other important functional areas, the comprehensive regulatory framework and already established safety standards only a limited number of research and statistics on the safety and compliance of pilot transfer arrangements have been found. The importance of performing the research on PTA lies in the high volume of non-compliant transfer arrangements identified throughout the industry [16]. This rises the safety concerns of pilot operations, especially while boarding and landing vessels.

The purpose of this study is to compare the interrelated system of regulations, recommendations, industry standards, and procedures prescribed to ensure compliance and safety of pilot ladder utilization with pilot best practices and statistics to determine the ratio of non-compliant transfer arrangements in operation. As for the sources of literature study, the pilotage studies from relevant organizations and associations were used along with the regulatory documentation, scientific literature and reports concerning pilot ladder arrangements. The standards for pilot transfer arrangements are defined by the SOLAS regulation V/23, IMO guidelines Resolution A.1045 (27), the ISM Code procedure and ISO standard, in particular ISO 799:2019 standard, as a non-mandatory recommendation. The main objective of this research is to highlight the discrepancy and inconsistency within the regulatory framework concerning PTA and indicate high volume of non-complied arrangements on vessels. These provisions act as a critical point in the establishment of safe environment of pilot operations on vessels, so the necessity to eliminate the violation of safety standards and possibly human health consequences is of utmost importance.

2. ANALYSIS OF REGULATORY FRAMEWORK DEFINING PTA

PTA as a holistic system can be defined as a chain of individual regulatory components, aiming to ensure pilot safety during embarkation and disembarkation activities. From the safety perspective, the legislative regulating PTA consist of SOLAS regulation and IMO guidelines as a mandatory requirements, ISO standard which is seen as the good practice for ships and has a non-mandatory requirement, and ISM Code procedure. The chain-like system implies a supervising role of public and private entities on different parts of legal and safety framework considering pilot ladders. The main regulations dealing with PTA are shown in Figure 1.

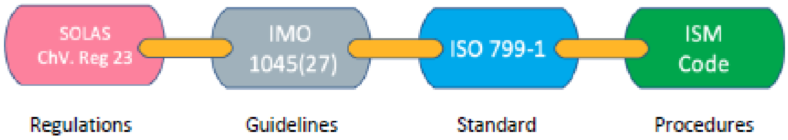


Figure 1 Interrelated system of individual regulatory components concerning PTA arrangements

Source: Broers, 2021a [17]

The use of pilot transfer arrangements were firstly prescribed by SOLAS regulation V/23 where four fundamental components were highlighted: requirements for pilot boarding arrangements, responsibilities for ship's personnel in rigging pilot transfer equipment, requirements for associated equipment and requirements for clear access and lighting [18]. The main outcomes of the SOLAS convention, considering PTA, are provided in Table 1.

Table 1 SOLAS provisions regarding PTA

SOLAS	MAIN OUTCOMES ON PTA
Requirements for pilot boarding arrangements	- efficiently fulfill the purpose of pilot embarking and disembarking safely, - keep the PTA clean, maintained, stowed and regularly inspected, - used solely for the embarkation and disembarkation of personnel, - accommodation ladder shall be used in conjunction with the pilot ladder, whenever the distance from the surface of the water to the point of access to the ship is more than 9 m.
Responsibilities for ship's personnel in rigging pilot transfer equipment	- the rigging of PTA and embarkation of pilot should be supervised by responsible officer, having communication with bridge, - the responsible officer will arrange for the escort of the pilot a safe route to and from the bridge, - personnel shall be instructed of the safe procedures to be adopted, and the equipment shall be tested prior to use
Requirements for associated equipment	- two man-ropes of not less than 28 mm and not more than 32 mm in diameter, - a lifebuoy equipped with a self-igniting light, - a heaving line when required, - stanchions and bulwark ladders adequate lighting to illuminate the transfer arrangements over-side, and the position on deck where a person embarks or disembarks.

Source: SOLAS, 2012 [18]

The SOLAS convention also indicates the importance of certification, marking, and record-keeping providing the requirement to enable the pilot to embark and disembark safely on either side of the ship. There are basically several arrangements used for efficient pilot transfer on vessels which are used in diverse conditions prescribed by regulations, including the use of the single pilot ladder, combination ladder, trapdoor arrangement as a special kind of combination ladder and the use of pilot ladder winch reels. All these arrangements are based on the use of pilot ladder as a tool so the purpose of regulative documentation should strive to ensure that the pilot ladders are rigged, used, maintained and handled in a safe and professional manner [19]. The use of a pilot ladder is the safest and efficient method to board ships at sea, and often without alternative, except when helicopter is used for the pilot transfer [20]. The SOLAS Convention defines the conditions and guidelines for rigging the single pilot ladder and accommodation ladder (i.e. a combination arrangement). These requirements are shown in Table 2.

Table 2 Requirements for single pilot ladder and accommodation ladder according to the regulation V/23 of SOLAS Convention

SINGLE PILOT LADDER	COMBINATION ARRANGEMENT
- climb of not less than 1,5 m and not more than 9 m above the surface of the water	- the accommodation ladder shall be sited leading aft
- clear of any possible discharges from the ship	- means to secure the lower platform of the accommodation ladder firmly to the ship's side
- placed within the parallel body length of the ship; within the mid-ship half length of the ship	- the lower end of the accommodation ladder should be within the parallel body length of the ship; within the mid-ship half length
- each step must rest firmly against the ship's side	- the lower end of the accommodation ladder should be clear of all discharges
- the single length of pilot ladder is capable of reaching the water and allowance is made for all conditions of loading and trim of the ship, and for an adverse list of 15°	- means to secure the pilot ladder and manropes to the ship's side at a point of nominally 1,5 m above the bottom platform of the accommodation ladder
	- when there is a trapdoor in the bottom platform, the pilot ladder and man ropes shall be rigged through the trapdoor extending above the platform to the height of the handrail

Source: SOLAS, 2012 [18]

Regarding the requirements for the adequate access to the ship's deck, the SOLAS regulation V/23 prescribes the existence of safe, convenient and unobstructed passage between the head of the pilot ladder (or accommodation ladder) and the ship's deck, adequate handholds in the case of using a gateway in the rails or bulwark, two handhold stanchions rigidly secured to the ship's structure at or near their bases and at higher points when bulwark ladder is used, and the obligation to securely attached bulwark ladder to the ship to prevent overturning [18]. All the provisions of regulation V/23 of SOLAS Convention were considered in the adoption of IMO Resolution A.1045 (27) in 2011 [21], which provided a detailed overview of recommendations on pilot transfer arrangements. The resolution set the minimum standard on the arrangement of a pilot ladders and specified the requirements of an individual structural element of the equipment used. The main findings of IMO resolution on pilot ladders and accommodation ladders are presented in Table 3.

Table 3 Main guidelines of IMO resolution A.1045 (27) on pilot and accommodation ladders

IMO SECTIONS		RECCOMENDATIONS
Pilot ladders	Positon and construction	- securing strong points, shackles and securing ropes should be at least as strong as the side ropes Steps: - made in one piece, free of knots; four lowest steps may be of rubber; non-slip surface; specifications on dimensions; secured to remain horizontal - no more than two replacement steps, - pilot ladders with more than five steps should have spreader (adequate dimensions), - the lowest spreader step should be the fifth step form the bottom, - retrieval line should be fastened at or above the last spreader step and should lead forward - permanent marking throughout the length of the ladder
	Ropes	- side ropes should consist of two uncovered ropes not less than 18 mm in diameter on each side, - should be continuous, with no joints and have a breaking strength of at least 24 KN per side rope, - continuous length of rope, made of manila or other material, - secured together both above and below each step with a mechanical clamping device or seizing method with step fixtures (chocks or widgets)
Accommodation ladders		- length: angle of slope does not exceed 45°, - lower platform should be in a horizontal position, secured to the ship's side when in use, and positioned minimum of 5 m above sea level, - the ladder and platform should be equipped on both sides with stanchions and rigid handrails, - the pilot ladder should be rigged immediately adjacent to the lower platform of

	the accommodation ladder and the upper end should extend at least 2 m above the lower platform - the horizontal distance between the pilot ladder and the lower platform should be between 0.1 and 0.2 m, - if a trapdoor is fitted in the lower platform to allow access from and to the pilot ladder, the aperture should not be less than 750 mm x 750 mm., - the trapdoor should open upwards and be properly secured, and the pilot ladder should extend above the lower platform to the height of the handrail and remain in alignment with and against the ship's side.

Source: IMO, 2011 [21]

The remaining sections of IMO resolution specifies guidelines on the use of mechanical pilot hoists, recommendations on accessing to the ship's deck and safe approach of the pilot boat, with the provisions of the procedures when installing the pilot ladder winch reels for pilot transfer activities. When accessing the ship's deck there is a requirement to ensure safe, convenient and unobstructed passage to pilots by providing adequate handholds at the point of embarking and disembarking from the ship, regardless of the means for the access which include a gateway in the rails or bulwark and bulwark ladder [21]. Both the SOLAS and IMO resolution indicate the obligation of pilot ladder certification, referring to the ISO standardization in the document text, in particular ISO 799:2019. This document further specifies the requirements for the pilot ladders when used for safe pilot transfer against a vertical portion of the hull of the ship [22]. As the pilot ladders are part of the safety equipment onboard cargo ships over 500 GT, and are mentioned in the cargo ship safety equipment certificate, they should be inspected before every use and on regular basis based on the ship maintenance system (SMS), under the governing ISM code certification [23]. It should be emphasized that all the provisions of different regulations are in certain way interconnected, creating a regulative system of specific set of rules, recommendations, and guidelines.

3. EMPIRICAL AND THEORETICAL EVIDENCE OF QUESTIONABLE APPLICATION OF SAFETY STANDARDS AND NON-COMPLIANT PTA

3.1.Empirical analysis of PTA deficiencies

Despite the precise and strict regulatory framework and predefined set of rules, to verify the productivity of the legal provisions application it is needed to evaluate individual inspection reports and statistics on different violations and deficiencies of pilot transfer arrangements. There are no official statistics from relevant bodies considering the ratio of non-compliant PTA. These circumstances surely contribute to the uncertainty of compliance and actions performed to enhance safety on ships during pilot's boarding and disembarking of vessels at sea. Very few analysis have been performed continuously on a yearly basis, among which the research conducted by International Maritime Pilot Association (IMPA) is considered as the most relevant and comprehensive. The study of IMPA is based on the contribution of numerous pilot organizations, and can be considered representative and indicative to provide general conclusions on the subject. There are four main research categories included in the study, participants, vessel type, compliance by means of transfer and non-compliance by type of defect. During the years the safety campaign evolved, contributing with more than 6,000 reports in 2020, a generated increase of 236%. The reasons of the exponential increase can be found primarily in intensifying activities of South American pilots, in terms of significant growth of percentage rate of returned observations. Table 4. shows the total number of reports for each geographical area with accompanied percentage change among the analyzed years.

Table 4 Number reports regarding PTA on vessels based on the geographical area in the period 2016-2020

NUMBER OF REPORTS							
Region	2016	2017	2018	2019	2020	Percentage 2020/2019	Percentage 2020/2016
Africa	25	55	100	43	173	402%	692%
Asia & Oceania	420	515	810	886	912	103%	217%
Europe	1.636	1.228	1.679	1.743	1.718	99%	105%
Middle East	0	0	79	4	31	775%	/
North America	127	160	371	209	415	199%	327%
South America	501	901	1300	1.340	3.145	235%	628%
TOTAL	2.709	2.919	4.339	4.225	6.394	151%	236%

Source: IMPA, 2016-2020 [24]

Besides the number of returned reports on the different geographical region basis, an indicator of non-compliant pilot ladders in use outlines the foundation for the evaluation of applied regulatory amendments on vessels considering pilot transfer arrangements. The overall trend percentage for the analyzed period (2016-2020) has a descending character, where the use of non-compliant pilot ladders has decreased from 18% in 2016 to 12% in 2020. However, due to the growth of returned reports, the absolute value of non-compliant PTA in use has increased by almost two times. In accordance with the data provided in Figure 2, there has been noted a high percentage variation of non-compliant PTA in the Middle East and Africa and a strong decrease in South American region.

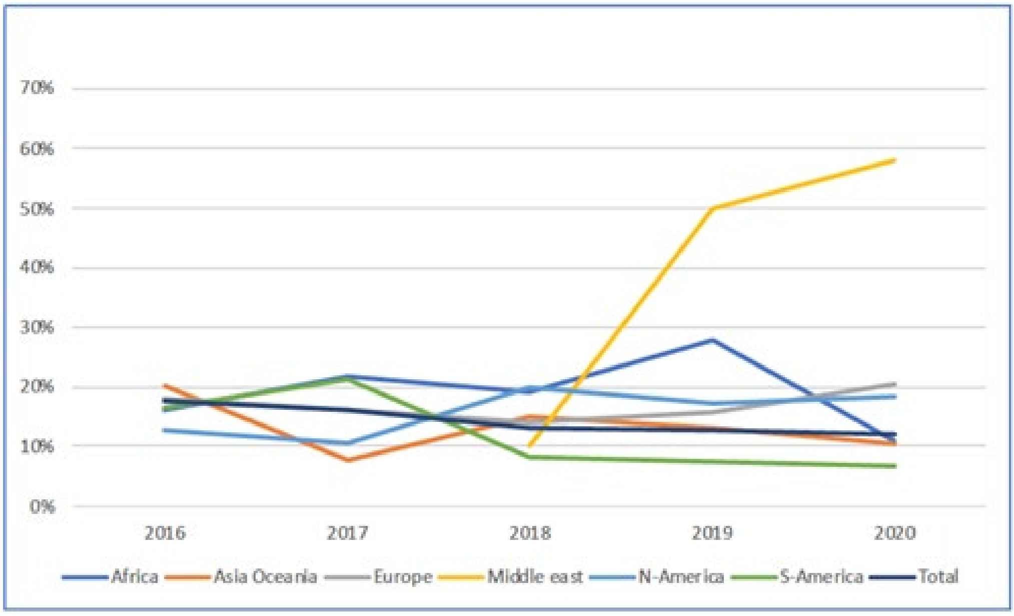


Figure 2 Percentage of non-compliant pilot ladders by region in the period 2016-2020

Source: IMPA, 2016-2020 [24]

When analyzing the level of PTA deficiencies it is necessary to determine the percentage of the returns e.g. non-complacencies found of all the surveys performed by the criterion of the ship type. It enables to draw conclusions on the change of technical measures implementation to increase pilot safety when performing extremely hazardous undertaking of embarking and disembarking of ship. Table 5. shows the percentage of non-compliant vessels on which deficiencies were found by ship type.

Table 5 Percentage of non-compliant surveyed vessels by ship type in the period 2016-2020

PERCENTAGE OF NON-COMPLIANBY SHIP TYPE (%)					
SHIP TYPE	2016	2017	2018	2019	2020
General cargo	22	17	16	12	14
Oil tanker	14	17	12	14	9
RO-RO	18	16	9	13	13
Passenger ship	12	11	11	6	21
Containership	17	14	12	10	12
Gas tanker	11	13	7	11	13
Reefer ship	17	21	18	14	19
Fishing ship	33	40	38	37	15
Bulk carrier	23	17	17	16	12
Chemical tanker	10	21	13	11	16
Car carrier	8	5	10	11	7
Rig supply vessel	23	22	16	17	8
Other (e.g. navy)	28	22	12	18	15

Source: IMPA, 2016-2020 [24]

Data provided in table 5. indicates a significant percentage decrease of non-compliant pilot ladders rigged in almost all the observed ship types, except for passenger ships, and gas, reefer, and chemical tankers throughout the observed period. The highest decrease on non-compliant pilot ladders in 2020 was recorded among the fishing vessels, while the most deficiencies were reported for passenger ships. However, the difference between the categories with highest and lowest percentage of recorded deficiencies was decreased from 25% in 2016 to 14% in 2020. The focal point of conducted research is the PTA analysis of compliance by means of transfer and non-compliance by type of defect. It is the most essential data and crucial indicator in validation of applying the procedures according to the legal framework set. The percentage of non-compliant means of pilot transfer in presented in Figure 3.

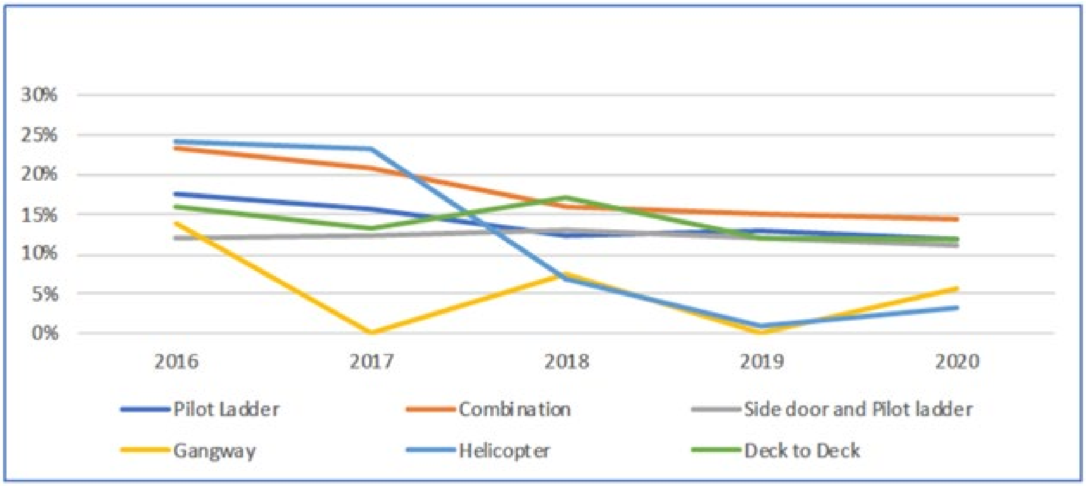


Figure 3 Percentage of non-compliance by transfer type in the period 2016-2020

Source: IMPA, 2016-2020 [24]

The overall data on the percentage of non-compliant means of pilot transfer in the period 2016-2020 shows decreasing trend for all the pilot transfer types analyzed. The largest percentage of deficiencies on non-compliant pilot ladders is accompanied with the use of combination ladder while a helicopter transfer has recorded the lowest percentage in 2020. The research data also indicate a persistent percentage level of non-compliant pilot ladder utilization. Considering the analysis of non-compliance by type of defect as a percentage of the total number of non-compliant reports, there is evident predomination of pilot ladder category (51% in 2020) recording an almost constant values throughout the observed period 2016-2020. However, the percentage of safety equipment deficiencies as a type of defect decreased form 31% in 2016 to 12% in 2020 (Figure 4.).

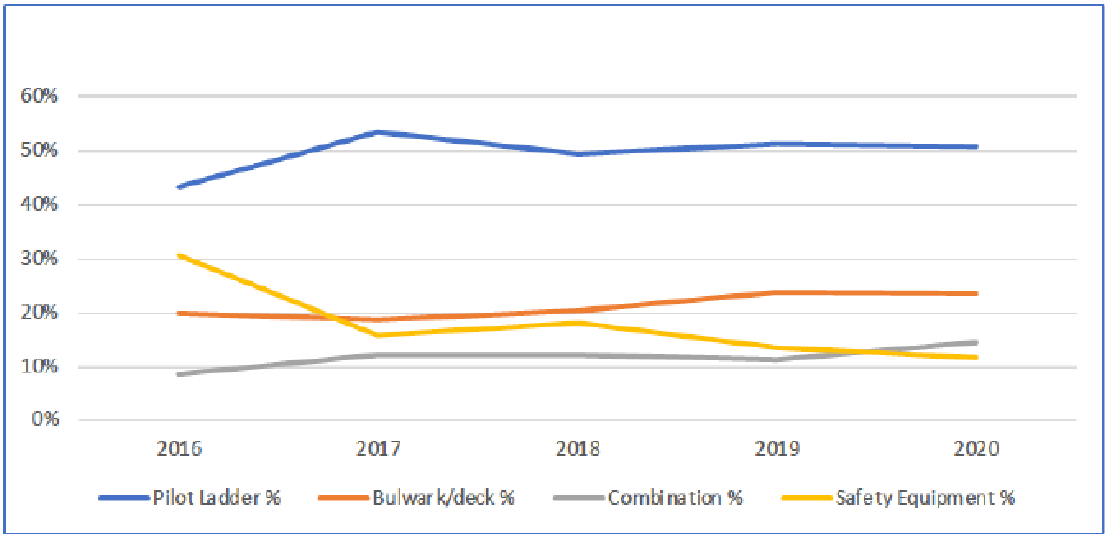


Figure 4 Percentage of non-compliance by type of defect in the period 2016-2020

Source: IMPA, 2016-2020 [24]

During the observed period (2016-2020), the most frequent types of the pilot ladder defects were indicated and analyzed. Based on the data provided in Table 6, the deficiency type of poorly rigged retrieval line showed significant increase during the years, an increase of 10% compared to the values recorded in 2016. Among the total defects in 2020, the most frequent selected were the conditions where the pilot ladder was not adequately positioned against the ship's hull (10%), the steps were not positioned horizontally (18%), already mentioned condition where retrieval line was rigged poorly (21%) and other deficiencies (24%).

Table 6 Pilot ladder deficiencies by type in the period 2016-2020

PILOT LADDER DEFECT BY TYPE (%)					
Type of defect	2016	2017	2018	2019	2020
Not against ship's hull	15	13	12	11	10
Steps not of suitable material	3	3	2	1	1
Poorly rigged retrieval line	11	16	11	14	21
Steps broken	6	2	3	2	3
Steps not equally spaced	3	5	5	5	4
Pilot ladder more than 9 m	2	2	2	2	1
Steps dirty / slippery	4	4	4	3	4
Sideropes not of suitable material	3	2	4	3	1
Pilot ladder too far forward / aft	8	3	3	3	3
Steps painted	1	1	2	1	3
Incorrect step fittings	7	5	6	4	5
No bulwark ladder	3	2	2	1	1
Steps not horizontal	18	17	18	17	18
Other	16	27	27	32	24
TOTAL	100	100	100	100	100

Source: IMPA, 2016-2020 [24]

The study also considered the examination of most common defects of bulwark and other deck arrangements, where 72% of total non-compliances in 2020 were related to the conditions of not properly secured ladder while the remaining percentage was allocated to faulty handhold stanchions defect (17%), and other bulwark and deck deficiencies. Figure 5 indicates bulwark and deck defects.

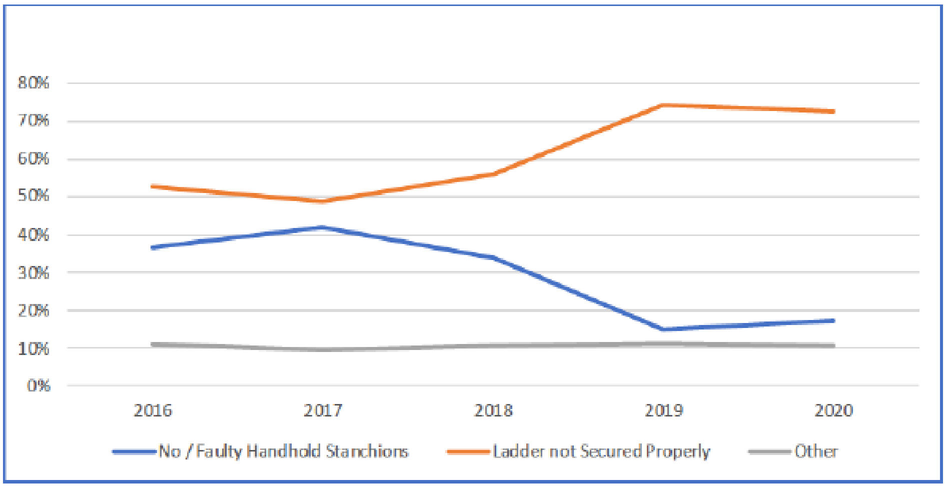


Figure 5 Percentage of non-compliance by defects of bulwark / deck in the period 2016-2020

Source: IMPA, 2016-2020 [24]

The comparison between the total of 6.394 observations provided in 2020 and the overall number of 183 reports allocated to the observations when the pilot ladder was not properly secured, it can be concluded that the percentage rate over the last five years also shows an upward trend (2,9% in 2020 vs 2,7 in 2016). On the other hand, the most frequent combination defects in 2020 were those related to not properly secured ladder to the ship's side (21%) and the conditions where pilot ladder was not attached 1,5 m above the lower platform of the accommodation ladder (24%), having the steady percentage rate during the reported period. Figure 6 indicates the combination defects by defect type in the period 2016-2020.

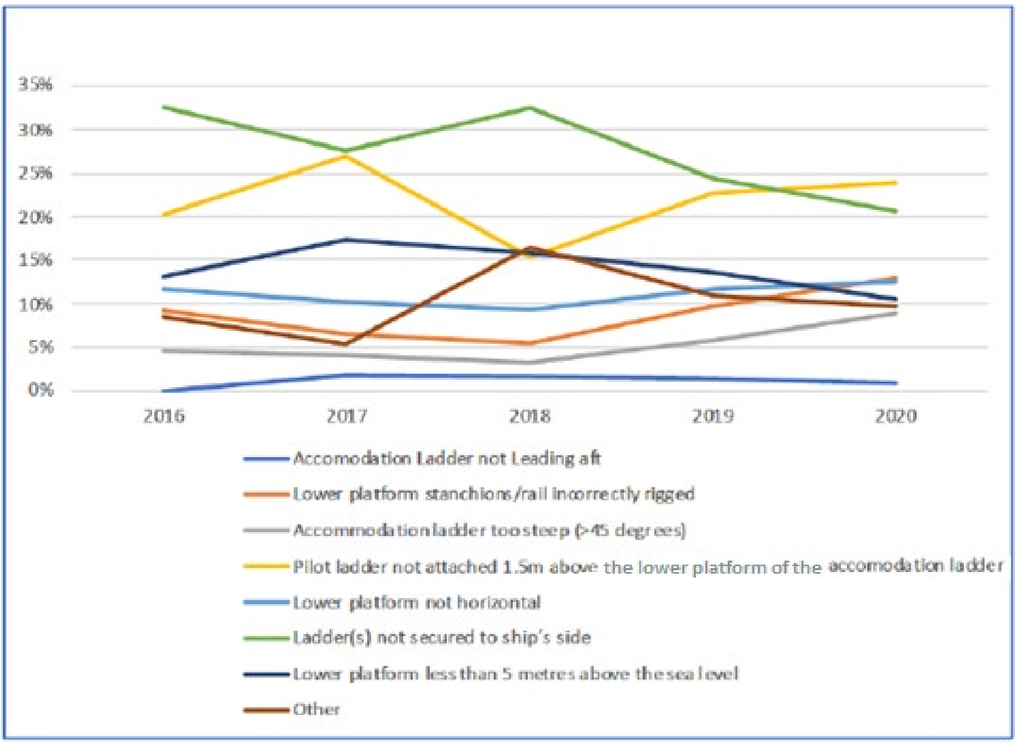


Figure 6 Percentage of combination defects by defect type in the period 2016-2020

Source: IMPA, 2016-2020 [24]

Furthermore, the research analyzed the most common safety equipment defects by defect type in a five year period. The research findings showed the highest percentage for the deficiency of no lifebuoy with self-igniting light (29%), followed by the inadequate lighting at night and no heaving line (21%) and the shortage of the attendance of responsible officer which has been recorded in 18% of reports. The deficiency regarding the inadequate lighting at night showed significant increase in the observed period while cumulative percentage of non-compliances considering the safety equipment decreased over the last five years. The data is shown in Figure 7.

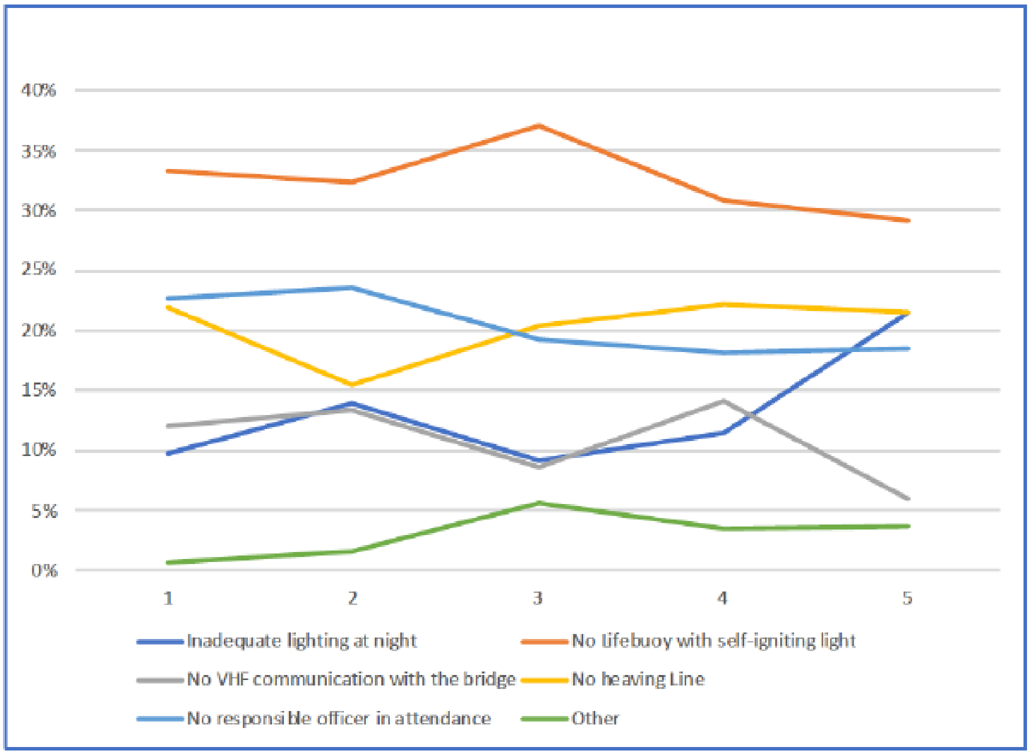


Figure 7 Percentage of safety equipment defects by defect type in the period 2016-2020

Source: IMPA, 2016-2020 [24]

In general, the IMPA reported the average rate of 14,3% of non-compliant PTAs of all the ship types in 2018, 2019 and 2020. However, the statistical analysis performed by Tokyo MOU showed only 0,25% of PTA deficiencies related to the number of ships identified of total ships inspected in 2015 and 2017. Also, the number of PTA related deficiencies accounted for 0,38% of all deficiencies identified [14]. Rattray [25] states that the rate of non-compliant PTA on vessels trading in Europe is close to 21%.

Apart from the presented research statistics, there is also another research performed in 2019, which dealt with the analysis of pilot ladder fallings, based on the reports of Confidential Human Factors Incident Reporting Programme (CHIRP). The objective of the analysis of received reports on pilot ladder deficiencies and pilot fallings was to indicate the segments of the overall process where the deficiencies occur. In 2019, there were 124 reports recorded related to the issue of pilot ladder fallings and deficiencies in pilot ladder and combination ladder rigging. The reports were divided into main areas and analyzed to determine the actions needed. The report indicated that of total number of deficiencies, 62% were related to the ships built before the current SOLAS Chapter V Regulations in 2012, while the remaining 38% were the ships built 2012 or later. Considering the reports which were specific to pilot ladders deficiencies, 66 of them related to a single ladder utilized for pilot embarkation and disembarkation. On the other side only 17 reports were reported as accommodation ladder deficiencies [26]. Figure 8 shows the specific deficiencies of reports related to single pilot ladder and accommodation ladder.

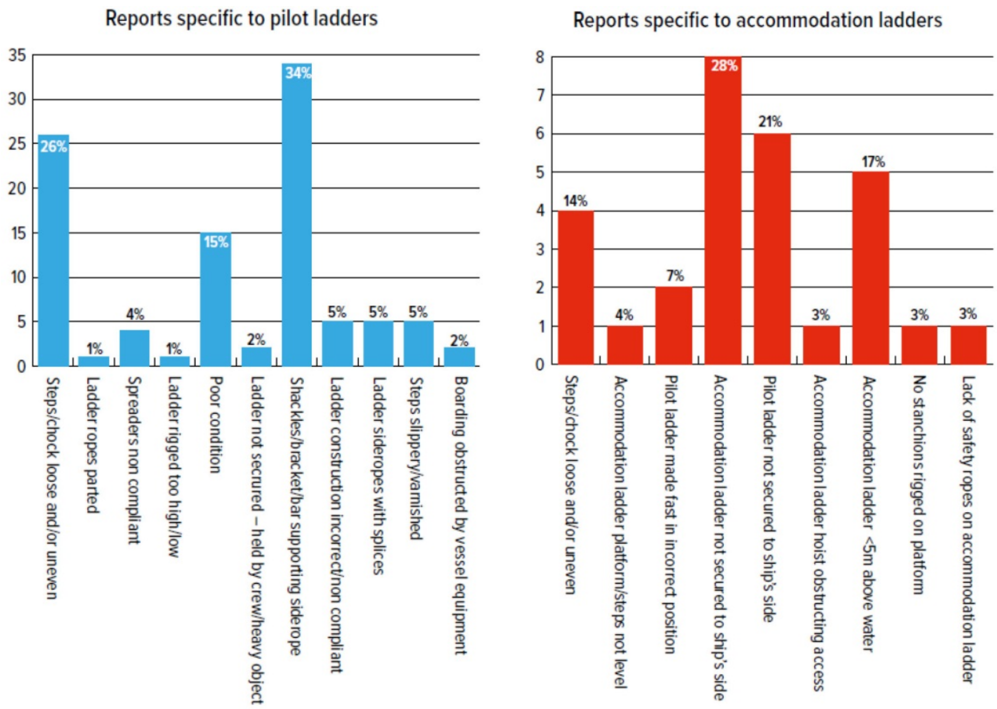


Figure 8 Reports specific to pilot ladders and accommodation ladders in 2019

Source: CHIRP Maritime, 2020 [26]

More than one third of all the pilot ladder deficiencies recorded were related to the side ropes which were supported by shackles, a bar or a bracket. This arrangement is in collision with the safety standards, despite the provisions of SOLAS where the regulation did not explicitly stated the method of securing the side ropes but only the obligation that the arrangement must be the same or greater strength than the side ropes. The remaining significant deficiencies were the poor condition of the pilot ladder and uneven and/or loose steps or chocks. In contrary, almost 50% of all deficiencies considering accommodation ladders were related to accommodation ladder or pilot ladder which was not secured to the ship's side as required by the 2012 SOLAS V regulations. Also, a significant share was related to failure of the accommodation ladder which was less than five meters above the waterline. The remaining report areas were related to the reports of trapdoor arrangements, manrope deficiencies and sundry equipment deficiencies (Figure 9.).

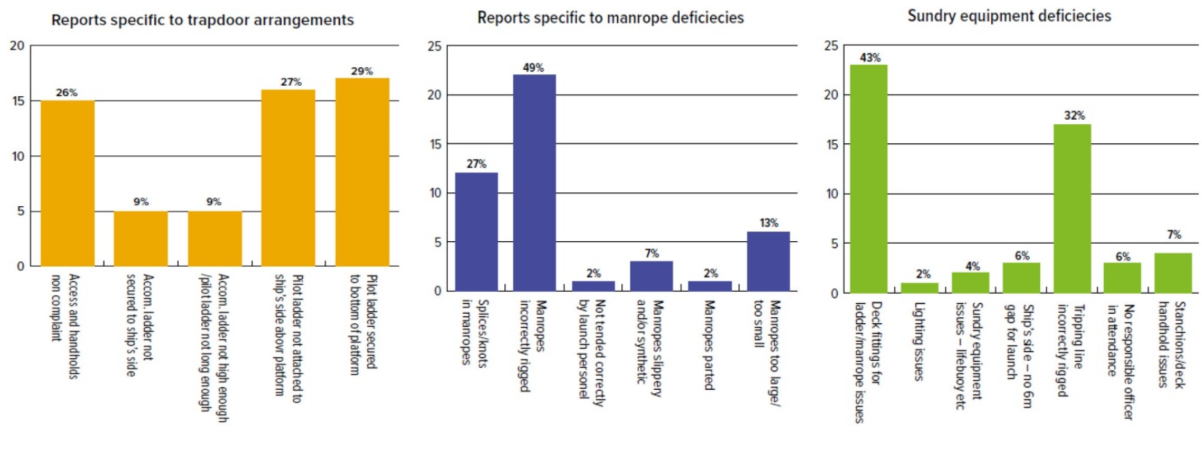


Figure 9 Reports specific to trapdoor arrangements, manrope deficiencies and sundry equipment deficiencies in 2019

Source: CHIRP Maritime, 2020 [26]

There were 25 reports related to trap door arrangements recorded, 37 reports on manrope deficiencies and 47 reports on sundry equipment deficiencies. Considering the trapdoor arrangements deficiencies, the highest percentage was found in the categories when the pilot ladder was secured to the bottom of the accommodation ladder (29%), the pilot ladder (often another ladder) was not being attached to the ships side 1,5 m above the accommodation ladder platform (27%), and the access and handholds were non-compliant (26%). Almost half of all deficiencies regarding the manropes were related to incorrect rigging (49%), while the highest percentage of pilot fallings in sundry equipment deficiencies were affiliated with lack of deck fittings for side ropes and manropes (43%) and incorrectly rigged tripping line (32%).

The analysis of the two independent studies show important but rather worrying conclusions considering the compliance of the PTAs with the safety measures and amendments of the 2012 SOLAS Regulations and the accompanying IMO Assembly Resolution A.1045(27). The correlation of the results generated is highlighted in the principal deficiency, rigging the pilot ladder which often results with pilot fallings and other safety violations which could potentially jeopardize the pilot's health condition. Besides the defects of equipment and diverse pilot transfer arrangements, there is also an issue of quality of training and supervision. These circumstances questions the on-board safety culture and meeting the required minimum safety standard.

3.2. Inconsistency between regulatory framework

The increased number of deficiencies and non-compliant PTAs should also raise the question of harmonization and consistency between the main regulations. As already stated, SOLAS Convention (Chapter V, Regulation 23) sets out the principal requirements for the rigging of a pilot ladder, which are further detailed in the technical specification for pilot ladder in IMO Resolution A.1045 (27). Also, the PTA should comply with ISM Code and voluntary ISO standards and procedures. This legal framework is prescribed to ensure the proper provision for safety standards of pilot operations. Besides the influences on the pilot's health, the violation of safety standards is also reflected in delays and financial penalties towards the ship operator. It is essential to eliminate the discrepancy between the regulations and guidelines regarding the pilot ladder safety at embarking and disembarking activities. Based on the comparison among the amendments of the regulatory framework and pilots' best practice and experience, the critical points and ambiguous patterns are provided. The main discrepancies between the regulations and guidelines regarding the pilot ladder safety are provided in table 7.

Table 7 Main discrepancies between the regulations and guidelines regarding the pilot ladder safety

CRITICAL POINT	SOLAS	IMO	ISO
Mechanical clamping device	Pilot ladder certified by the manufacturer as complying with this regulation or with ISO 799:2019	Each pair of side ropes should be secured together both above and below each step with a mechanical clamping device properly designed for this purpose, or seizing method with step fixtures (chocks or widgets)	Mechanical clamping device is deleted
Pilot ladder certificates	A pilot ladder shall be certified by the manufacturer as complying with this regulation or with an international standard acceptable to the organization (ISO 799:2004 red.). Ladders shall be inspected in accordance with the regulations I/6,7 and 8	A pilot ladder should be certified by the manufacturer as complying with this section or with the requirements of an international standard acceptable to the organization (ISO 799:2004)	Voluntarily standard (not mandatory)
Securing the pilot ladder to the vessel at an intermediate length due to varying freeboard	/	Thimble eye included in the pilot ladder construction	Thimble eye included in the pilot ladder construction

Compliance of PTA on ships built before July 2012	Equipment and arrangements for pilot transfer which are installed on or after 1 July 2012 shall comply with the requirements of this regulation, and due regard shall be paid to the standards adopted by the Organization Equipment and arrangements for pilot transfer which are provided on ships before 1 July 2012 shall at least comply with the requirements of regulation 17 (resolution MSC.99(73) or 23, as applicable, of the SOLAS 1974	/	/
Low freeboard transfers	Not specified explicitly.	Not specified explicitly.	/

* Table cells marked with symbol "/" indicates that the individual critical point is not referred to the specific regulation

Another critical tool constantly being used in practice is an IMPA's pilot ladder poster, which is often displayed on the ship's bridge (Figure 10).

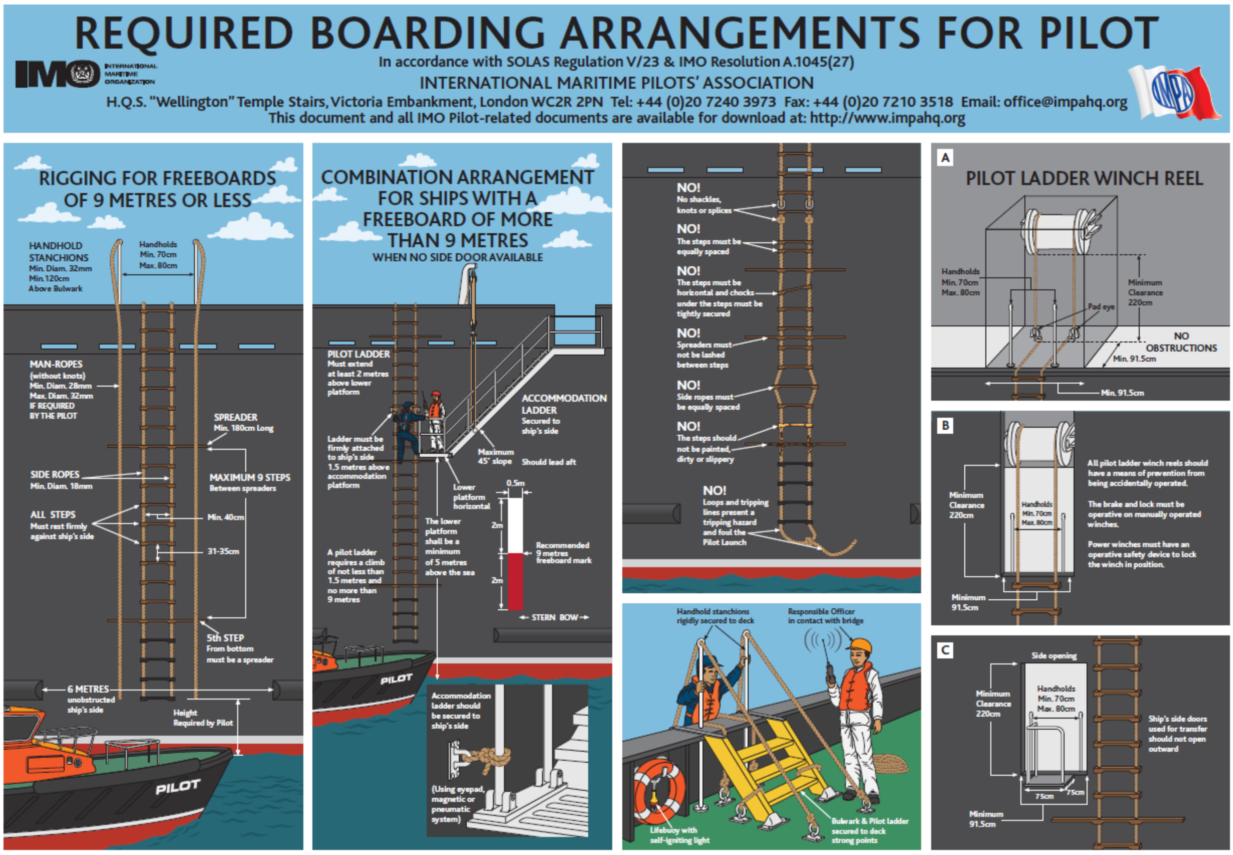


Figure 10 IMPA pilot ladder poster

Source: IMPA, 2020 [27]

The ship's crew frequently use the guidelines provided in the IMPA poster rather than fulfilling the requirements of prescribed set of rules and regulations [28]. By analyzing the mentioned pilot ladder poster, some elements were found non-compliant with the SOLAS and IMO requirements. These requirements should be updated along with other deficiencies to standardize the procedures intended to improve pilot safety according to the relevant regulations and rules. The highlighted discrepancies in the poster are shown in Table 8.

Table 8 IMPA pilot ladder poster deficiencies

COMBINATION ARRANGEMENT	BULWARK	PILOT LADDER WINCH REEL AND SIDEDORS
Pilot's step from the ladder to the platform	Pilot ladder without thimble eyes at the top end	The other ways are also possible to guide the ladder from vertical to horizontal, besides the pad eyes (Figure A)
Wrong position of the pilot mark	Pilot ladder secured with a wrong knot	The pilot ladder should be secured to a strongpoint, independent of the pilot ladder winch reel
Crew member welcoming the pilot	The same deficiency is related to side ropes	The pilot ladder should be secured at deck level inside the ship opening or, when located on the ship's upper deck at a distance of not less than 915 mm measured horizontally from the ship's side inwards
Both the gangway and the pilot ladder can be secured to the ship's hull by means of rope and magnet	/	The pilot ladder should be secured to the ship's hull 1,5m above the platform

* Table cells marked with symbol "/" indicates the non-existence of additional deficiency of individual equipment

Source: Palmers, 2020 [28]

It should also be added the deficiency of the correct procedure of rigging a trapdoor arrangement on the poster. Furthermore, in the combination section it is indicated that "a pilot ladder requires a climb of not less than 1,5m and not more than 9m", a statement which is in collision with SOLAS V/23, where the section 3.3.1. states: "pilot ladder requiring a climb of not less than 1.5 m and not more than 9 m above the surface of the water so positioned and secured that.." The mentioned deficiency of the poster content implies that pilot is allowed to climb a ladder despite the required height above the water which depends on the pilot assessment. This should be corrected and improved primarily as for the increased possibility of fatal injuries if falling from a height of more than 9 meters. This is due to fact that the increase in height of the pilot ladder, the speed of falling also increases (e.g. falling from 10 m increases the dropping speed to 50,4 km/h) [28].

The ultimate discrepancy relates to the no-compliance with the determined set of rules referring to the grandfather clause. It enables the vessels being built before 2012 to not comply with the indicated rules and revised regulations (which came into force in 2015) considering the equipment and arrangements for pilot transfer, as 2012 was a year that SOLAS V/23 was implemented. These circumstances raise the question of the decision makers to fulfill the minimum standard of safety requirement and provide safe and convenient access to pilots on board ship.

These critical, redundant, and inconsistent points presented in the regulatory framework but also in practical guidelines and overall environment are needed to be clarified and harmonized to provide the users clear guidelines, incorporated in policy requirements.

4. DISCUSSION AND CONCLUSION

Based on the individual research conducted, analysis of the regulatory framework inconsistency and pilot's experience and best practices registered on the safety of transfer arrangements during embarkation and disembarkation operations of maritime pilots, recommendations on the improvement of the safety measures are highlighted. The research findings indicated the fundamental defects which were primarily associated with procedures and requirements of rigging the pilot ladder. Also, the technical aspect of combination ladders was among the major deficiencies occurred during the pilot transfer procedure. In contrary, some ambiguous elements were detected in the analysis of regulatory framework and frequently utilized IMPA pilot ladder poster which should be harmonized and clarified to standardize the application of procedures in practice and make them obligatory for all the subjects involved. This also relates to restrictive measures of referencing to grandfather clause for the vessels built prior to the implementation of the SOLAS regulation

V/23. The study performed by Rattray [25] identified in detail several key areas of the required improvement, which included the regulation itself, compliance, training culture, vessel design, and accident / incident investigation. These results generated are in close correlation with the objectives and contributions of this research. The conclusions of the present work identified main critical points which should be eliminated to establish a safe environment and policy towards PTA compliance. Also, the significant procedures of PTAs which are identified as the most frequent deficiencies occurred in the pilot transfer procedure are also highlighted, to prevent the potential pilot injuries and ensure the compliance with the SOLAS and IMO regulations. The main suggestions are indicated below:

- Securing a pilot ladder at intermediate lengths must be clearly regulated (the use of rolling hitch knot opposed to the use of shackles in securing the ladder to strongpoints on deck);
- Comply with the rule that the ladder (and platform in case of rigging a combination ladder) has to be secured to the ship's hull at 1,5 m above the platform (with the rope, magnet or similar equipment defined by regulations);
- The retrieval line should be rigged at or above the bottom spreader and lead forward;
- Ensure the safe pilot transfer from the ladder to the platform with stanchions and rigid handrails, or ropes (according to the regulative recommendations) equipped on both sides;
- Provide safe, convenient and unobstructed passage for any person embarking on, or disembarking from, the ship between the head of the pilot ladder, or of any accommodation ladder, and the ship's deck;
- In case of rigging a single pilot ladder, the securing points on deck should be at least strong as the side-ropes (eliminate the use of deck tongues or steel bars, rigging the ladder over the railing;
- The pilot ladder should have permanent marking at regular intervals, steps should be made of hardwood, in one piece and non-slippery and should comply with the prescribed amendments;
- The accommodation ladder when rigged should be sited leading aft, with maximum slope of 45 degrees;
- When using embarkation platform (trap door), the pilot ladder and manropes should be rigged through the trapdoor extending above the platform to the height of the handrail and against the ship's side;
- The rigging of the pilot transfer arrangements and embarkation of a pilot should be associated with safety equipment such as life jackets, harness, life lines and life buoys is in place to assure the safety of personnel;
- The role of responsible officer must be defined, establishing the quality of training process and supervision at the basic level;
- Apply the correct position of the pilot mark and illumination of PTA operations;
- There is a need to include maintenance and inspection as an obligatory amendments of SOLAS regulation V/23 as the life-saving appliances incorporated in SOLAS III/20;
- All the operations of maintenance, repairs and certification should be recorded;
- Ensure safe approach of the pilot boat;
- Establish an official continuous supervision and monitoring of activities in the form of yearly statistical analyses of deficiencies reported;
- Improve IMPA pilot ladder poster according to the recommendations.

The requirement of the use of rolling hitch knot opposed to the use of shackles in securing the ladder to strongpoints on deck should be emphasized. The research performed by Broers [29] on the securing methods of pilot ladders at intermediate length indicated, in the majority of observations (more than 50% of total 486), the use of D-shackles on-board with only 31% of the rolling hitch knot used. Previous studies [30] indicated that the use of D-shackles has only about 50% of the strength of the pilot ladder when secured at full length. The detailed elaboration of unsafe and non-compliant use of shackles over side ropes for securing the pilot ladder at intermediate lengths can be found in the work of Vallance [31]. The overall requirement and initiative is to build a new approach which would enable to perceive pilot ladder safety as a system (Figure 11.).

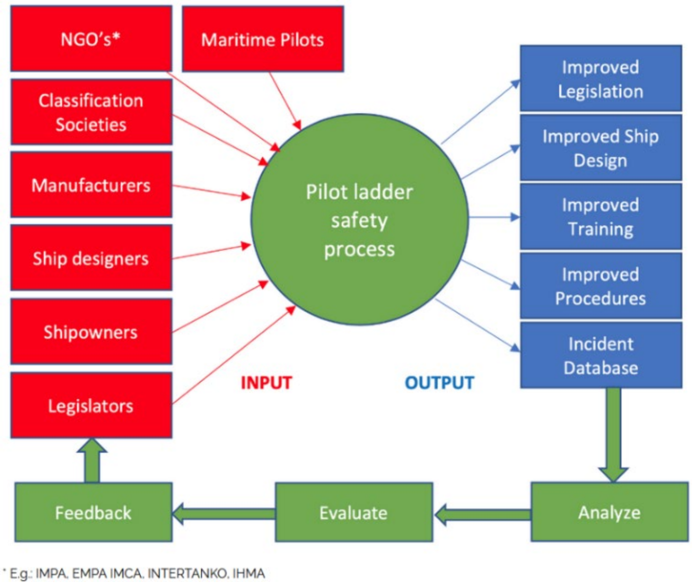


Figure 11 Recommended system regarding the pilot ladder safety

Source: Broers, 2020 [29]

This approach would involve all the stakeholders performing diverse activities in creating protocols. Considering the established connections between stakeholders involved, the repercussions of the process would result in constructive improvements in reaching the required safety standards. The safety problems arisen from deficiencies in rigging the pilot ladders and other arrangements, cannot only be associated to legislation and regulations, or the failure to comply with procedures and guidelines. Many of these deficiencies can be associated to the lack of training, bad seamanship, poor ship design or regulatory gaps.

REFERENCES

[1] Darbra, R.M., Crawford, J.F.E., Haley, C.W., Morrison, R.J. (2007) *Safety culture and hazard risk perception of Australian and New Zealand maritime pilots*. Maritime Policy. Vol.31, No.6. pp.736–745.

[2] Ernstsen, J., Nazir, S. (2020) *Performance assessment in full-scale simulators – A case of maritime pilotage operations*. Safety Science. Vol.129. No. 104775. doi:10.1016/j.ssci.2020.104775

[3] Uğurlu, Ö., Kaptan, M., Kum, S., Yildiz, S. (2016) *Pilotage services in Turkey; key issues and ideal pilotage.* Journal of Marine Engineering & Technology, 16(2), 51–60. doi:10.1080/20464177.2016.1262596

[4] Wu, L., Jia, S., Wang, S. (2020) *Pilotage planning in seaports.* European Journal of Operational Research. Vol.287. No.1. pp.90–105. doi:10.1016/j.ejor.2020.05.009

[5] UNCTAD (2018) Review of Maritime Transportation 2020. *Paper presented at the United Nations conference on trade and development*. New York and Geneva. URL: http://unctad.org/en/PublicationsLibrary/rmt2018 _ en.pdf .

[6] Lahtinen, J., Valdez Banda, O. A., Kujala, P., Hirdaris, S. (2020) *Remote piloting in an intelligent fairway – A paradigm for future pilotage.* Safety Science. Vol.130. No.104889. doi:10.1016/j.ssci.2020.104889

[7] van Erve, P., Bonnor, N. (2006) *Can the shipping-aviation analogy be used as an argument to decrease the need for Maritime Pilotage?*. Journal of Navigation. Vol.59. pp.359–363.

[8] Kujala, P., Hänninen, M., Arola, T., Ylitalo, J. (2009) *Analysis of the marine traffic safety in the Gulf of Finland*. Reliab Eng Syst Saf. Vol.94. No. 8. pp.1349–1357.

[9] Akten, N. (2004) *Analysis of shipping casualties in the Bosphorous.* Journal of Navigation. Vol.57. No.3. pp. 345-356.

[10] IMO (2011) Pilot Transfer Arrangements. International Maritime Organization, London.

[11] IMO (2012) Pilot Transfer Arrangements, Required Boarding Arrangements for Pilots. International Maritime Organization, London.

[12] ISPO (2015) International Standard for maritime Pilot Organizations. https://www.ispo-standard.com /~/media/SiteIspo/ISPO%20Standard/ISPO%20A%20-%2011%200.ashx [accessed: 21.03.2021.]

[13] Lee, J.W., Kim, E.W. Lee, C.H. (2017) *A Basic Study on the Accident Prevention Measures of Maritime Pilots during Embarkation and Disembarkation*. *Journal of Fishries and Marine Sciences Education*. The Korean Society for Fisheries and Marine Sciences Education. Vol.29. No.1. pp. 137–147. doi: 10.13000/jfmse.2017.29.1.137.
[14] IMO (2021). Considerations to improve the safety of pilot transfer arrangements Submitted by China, International Maritime Organization.
[15] European Commission Directorate-General For Mobility And Transport (2012) Study on Pilot Exemption Certificates. https://ec.europa.eu/transport/sites/transport/files/modes/maritime/studies/doc/2012-09-18-pec.pdf [accessed: 15.04.2021.]
[16] Rattray, E. (2021) Snakes or ladders a mixed methodology review into the boarding and landing of maritime pilots. https://www.maritimejournal.com/__data/assets/pdf_file/0024/1382253/Snakes-or-Ladders-A-MIXED-METHODOLOGY-REVIEW-INTO-THE-BOARDING-AND-LANDING-OF-MARITIME-PILOTS-1.pdf [accessed: 25.04.2021.]
[17] Broers, H. (2021a). Pilot ladder safety "Do it right, the first time". https://pilotladdersafety.com [accessed: 10.02.2021.]
[18] International Convention for the Safety of Life at Sea (1974) SOLAS Chapter V, Regulation 23 – Entry into force on July 1, 2012.
[19] Broers, H. (2021b). From Regulations and Guidelines to "Safety as a Total System" https://pilotladdersafety.com/from-regulations-and-guidelines-to-safety-as-a-total-system/ [accessed: 10.02.2021.]
[20] International Chamber of Shipping (2012) Shipping Industry Guidance on Pilot Transfer Arrangements Ensuring Compliance with SOLAS 2nd Edition. http://www.marinepilots.ca/presentations/pilottransferarrangementsbrochure.pdf [accessed: 25.01.2021.]
[21] International Maritime Organization (IMO) 2011. Resolution A.1045(27). https://wwwcdn.imo.org/localresources /en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.1045(27).pdf [accessed: 05.03.2021.]
[22] ISO (2019) Ships and marine technology — Pilot ladders — Part 1: Design and specification 799:2019. https://www.iso.org/standard/68808.html [accessed: 05.03.2021.]
[23] ISM Code (1998) International Safety Management Code, Resolution A.741(18). https://puc.overheid.nl/nsi/doc/PUC_2410_14/6/ [accessed: 05.03.2021.]
[24] IMPA (2016-2020). IMPA Safety Campaign. https://www.impahq.org/ [accessed: 25.01.2021.]
[25] Rattray, E. (2021). Snakes or ladders: A mixed methodology review into the boarding and landing of maritime pilots. Maritime Journal. https://www.maritimejournal.com/__data/assets/pdf_file/0024/1382253/Snakes-or-Ladders-A-MIXED-METHODOLOGY-REVIEW-INTO-THE-BOARDING-AND-LANDING-OF-MARITIME-PILOTS-1.pdf [accessed: 15.03.2021.
[26] Chirp Maritime (2020). Annual Digest Reports and Insight Articles MARITIME 2020. London, UK: The CHIRP Charitable Trust
[27] IMPA (2020). Pilot Ladder Poster. https://www.impahq.org/admin/resources/finalimpapladderposter.pdf [accessed: 15.03.2021.]
[28] Palmers, A. (2020). The IMPA Pilot Ladder Poster: Suggestions for Improvements. https://www.marine-pilots.com/articles/147387-impa-pilot-ladder-poster-suggestions-for-improvements [accessed: 15.03.2021.]
[29] Broers, H. (2020). Results of the online survey into the securing methods of pilot ladders. https://www.marine-pilots.com/articles/207553-results-online-survey-into-securing-methods-of-pilot-ladders [accessed: 15.03.2021.]
[30] Evans, T. (2020). Strength of Pilot Ladders and Intermediate Securing of Pilot Ladders: An investigation into actual strength of ladders and intermediate securing methods used. https://www.marine-pilots.com/articles/115222-update-strength-of-pilot-ladders-and-intermediate-securing-of-pilot-ladders [accessed: 15.03.2021.]
[31] Vallance, K. (2020). Securing pilot ladders at intermediate lengths. https://www.marine-pilots.com/articles/14029-securing-pilot-ladders-at-intermediate-lengths [accessed: 15.03.2021.]

VIDEO BASED NAVIGATION FOR AUV

Jacek Zalewski
Polish Naval Academy
Gdynia, Poland
E-mail: j.zalewski@amw.gdynia.pl

Leszek Pietrukaniec
Polish Naval Academy
Gdynia, Poland
E-mail: l.pietrukaniec@amw.gdynia.pl

UDK 004.89:629.56(204.1)

Summary

Currently, one of the main trends of modern marine technology is the development of unmanned vehicles. Their universality and versatility mean that they successfully carry out tasks that so far required the involvement of human resources. One of the problems that hinder the use of the AUV is proper navigation (the need to accurately determine the location). The solution presented in the article is to enable the determination of the AUV position based on the imaging of the surroundings above the water surface in the absence of access to radio navigation methods. For this purpose, computer vision techniques and artificial neural networks were used.

Keywords: Computer Vision, Deep Learning, Autonomous Underwater Vehicle, Navigation

1. INTRODUCTION

The marine environment is becoming more and more explored by man. This carries a lot of dangers because the human body is not adapted to staying under water for a long time. Currently, a lot of emphasis is placed on the development of unmanned vehicles [1]. Their universality and versatility mean that they are adapted to the implementation of many different tasks. This applies to both remotely controlled (ROV) and autonomous (AUV) vehicles.

One of the problems that hinder the use of the AUV is proper navigation. The oldest, known for ages, method of determining the position is the dead reckoning [4]. Currently, it is most often implemented on the basis of inertial systems, using Newton's principles of dynamics, such as accelerometers and gyroscopes. Knowing the course and speed of the vessel as well as the starting point, it is possible to determine the position in successive time intervals. The imperfection of the measuring sensors used and external factors cause, however, that we are dealing with the phenomenon of errors that accumulate in time, such as: drift, white noise, temperature effects and system calibration errors [7]. It is very important as these phenomena usually assume the nature of a linear or quadratic incremental function. As a result, there may be a situation in which the designated and actual position will differ significantly, significantly impeding or preventing the further performance of tasks by the AUV. The electronics used are increasingly accurate, but not perfect. In addition, factors generated by the marine environment, such as currents, waves and tides, often cause uncontrolled vehicle displacement, the value of which is usually difficult to quantify. Therefore, there is a great need to counteract these phenomena.

The error reduction can be performed through the use of radio navigation devices [5], mainly satellite. Sometimes, however, there is a situation in which the radio signal will be unavailable or intentionally disturbed [6]. Therefore, there is a need to build an alternative system [2].

2. PREPARATION OF RESEARCH

The article presents is an innovative method of determining the position of an autonomous underwater vehicle based on computer vision and artificial intelligence techniques. It is dedicated primarily to AUVs operating in an environment where there is no access to radio navigation signals, in particular GNSS. During a temporary ascent, the system records the image around the vehicle using a camera installed on the vehicle. Then, using a trained neural network, semantic segmentation is performed [3], the purpose of which is to obtain information about the height of the land in a given bearing. This creates a representation of the environment around the vehicle S^P, which is compared to its counterpart obtained from the site map for each randomly selected point.

1134 photos for 70 various locations of the Gulf of Gdańsk were used for the study. Their distribution is shown in Figure 1. Each shot includes information on the position and azimuth of the optical axis of the camera. These data were used to create a representation of the surroundings S^P in range from 0 to 360^0 for each of the points $P\ (\varphi, \lambda)$.

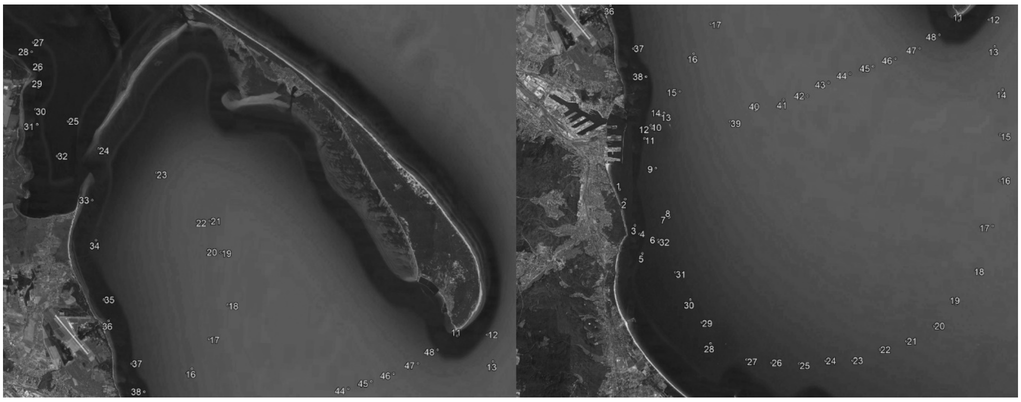


Figure 1 Distribution of measurement points

Source: own development based on Google Maps

An important subject for the user influencing the shaping is the height of the lens over the parameters of the water. It was assumed that the photos will be taken at a constant height of 1 meter above sea level. An Olympus camera with a digital GNSS receiver and a compass was used to take the shots. During recording, the focal length of the lens was set to a value equivalent to 25mm for a full-frame matrix, thus obtaining a HFOV (horizontal field of view) of 71.51 degrees. Full 360 image could be obtained by registering a minimum of 6 photos. In practice, this number ranged from 8 to 16.

During research in a marine environment, attempts were made to increase the focal length of the lens in order to obtain a more detailed image. However, it made it difficult to capture the correct frame, and the shots taken were very often blurry, especially in difficult lighting conditions.

Then, segmentation of all captured images is performed to determine where the land is. In the next step, information is aggregated from all N photos taken. Formally, the representation of the point$P(\varphi, \lambda)$ is $S^P = < S_0^P, S_1^P, \dots, S_t^P >$ where integer $r = round(\frac{360}{R})$, is a function of rounding to the nearest integer value and R is a parameter of the algorithm, resolution of S^P. $S_i^P, i \in < 0, \dots, S_t^P >$ is the height of the land as seen from point P in direction iR. S^P is determined from the N images captured by the camera, of which the k image is represented by:

$$A_k, S_k, k \in < 0, \dots, N > \qquad 1)$$

where A_k is the azimuth of the optical axis of the camera, and:

$$S_k = < S_{k0}, S_{k1}, \dots, S_{kW} > \quad 2)$$

is the land height vector for the kth image, $W = round\ (\frac{HFOV}{R})$, and $S(k)$ is the land height measured from the k image for (A_k-$\frac{HFOV}{2}$ + jR) the viewing angle. Finally, S_i^P is determined as follows:

$$S_i^P = \frac{S_{k,l}}{S_{k,l}^{max}} \quad 3)$$

$$S_{k,l}^{max} = \max_{k,l} S_{k,l} \quad 4)$$

$$k = {}^{argmax}_{\ \ \ \ \ \ \ \ k}|A_k - iR| \quad 5)$$

$$l = {}^{max}_{\ \ \ \ j}|iR - \left(A_k - \frac{HFOV}{2}\right) - jR| \quad 6)$$

The generation of comparison points requires reference to a map of the area where the AUV performs its tasks. The more precise it is, the more accurate the comparison point display will be. In this study, the sea map was used as the surroundings of which the comparative points are generated. Compared to other models, the sea map does not contain information on the height of individual objects (Figure 2).

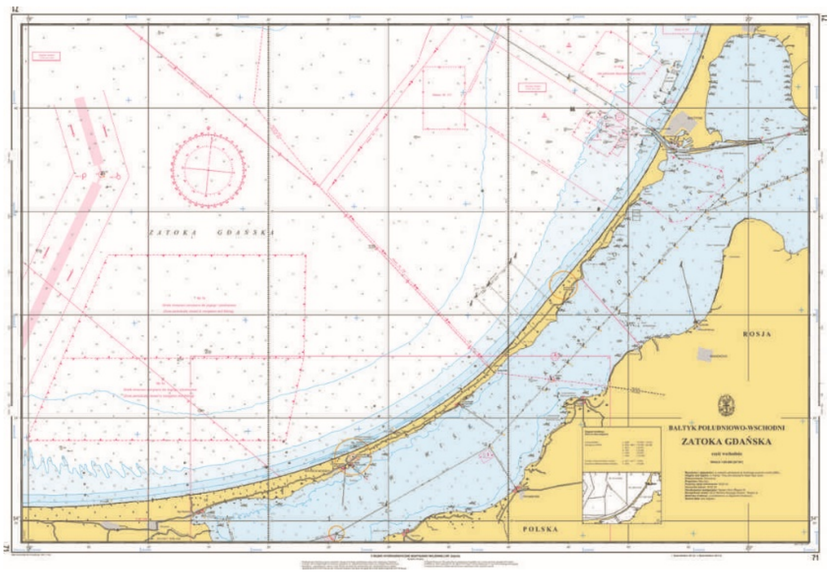


Figure 2 Sea map

Source: Polish Navy Hydrographic Office

The lack of information about the height of the objects is a problem especially in areas with a varied topography, as it is difficult to correctly determine the distance to the shore in this situation. Due to the fact that most of the coast in the Gulf of Gdańsk is covered with pine trees, it was assumed that the average height of the land would be 30 meters. This enabled the use of a previously developed algorithm for creating a map representation with the use of a numerical land cover model. It includes the application of appropriate transformations taking into account the curvature of the earth and mutual shading of objects. The farther we move away from the object, the more part of it becomes obscured. The size of the visible part of the object depends mainly on the height at which the camera was placed and the distance from the object (Figure 3).

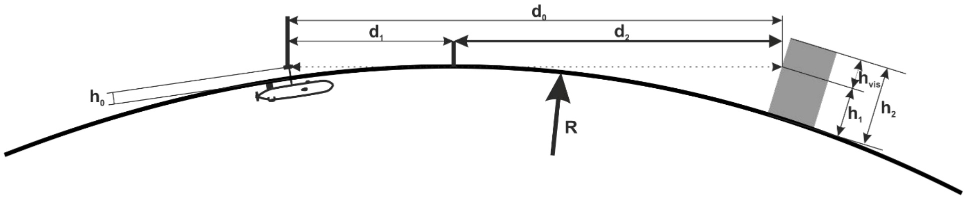


Figure 3 The method of determining the height of the seen land on a given bearing

Source: own development

$$d_1 = \sqrt{(R + h_0)^2 - R^2} \quad 7)$$

$$h_1 = \sqrt{R^2 + d_2^2} - R \quad 8)$$

$$h_{vis} = h_2 - h_1 = h_2 - \left(\sqrt{\left(d_0 - \sqrt{h_0(h_0 + 2R)}\right)^2 + R^2} - R\right) \quad 9)$$

where:

h_o − *high of camera*
R − *radius of Earth*
d_0 − *distance from the object*
h_1 − *height of the object*
d_1 − *distance from AUV to horizon*
d_2 − *distacne from horizon to object*
h_2 − *height of the object below horizon*
h_{vis} − *height of the object visible above horizon*

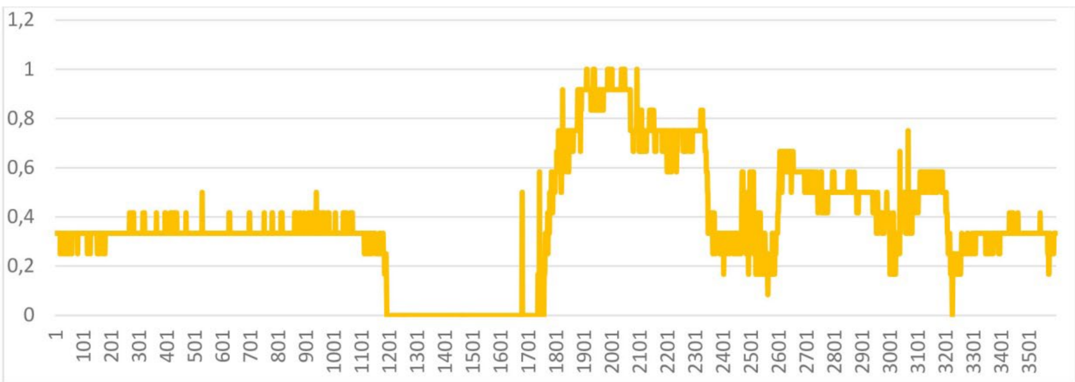


Figure 3 Representation of the surroundings S^P for the point P

Source: own development

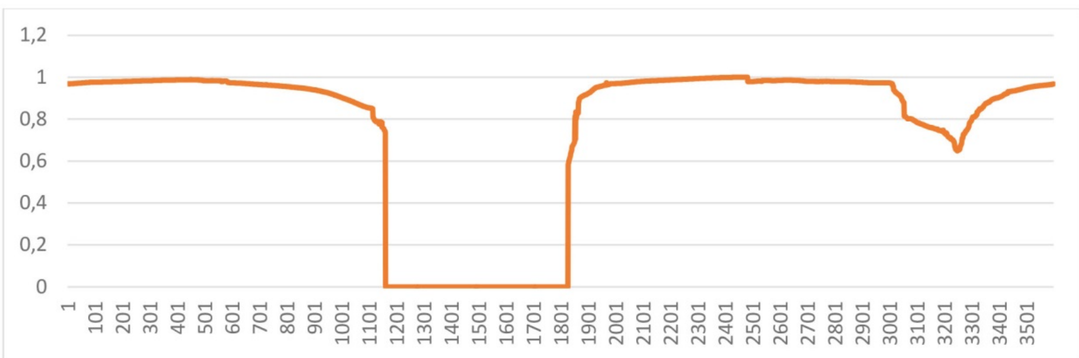


Figure 4 Map representation S'^P for the point P

Source: own development

In the next step, the position of the vehicle is estimated. This is done by comparing the representation of S^P with the map representations S'^G for the set $Z = < G_0, G_1, \dots, G_{|Z|} >$ random points located in the circle with radius r and center at point Q, determined on the basis of count navigation. The position of the point P corresponds to the position of the point G whose representation S'^G is most similar to the representation of S^P with respect to the selected measure of similarity T:

$$P = G_k,\ k = \operatorname{argmax}_{i \in 0 \dots |Z|} T(S^P, S'^{G_i}) \quad 10)$$

3. RESULTS

For all measurement points, the maximum similarity coefficient (A) ranged from 0.6 to 0.8 (where A ⊂ [-1.1]). Despite this, its increase did not cause a decrease in the error in determining the vehicle position (Figure 5). In addition, there were often situations in which initially the increase in the correlation coefficient caused the error to decrease and above a certain value to increase it again (Figure 6).

In the next stage, the representations of the S^P environment (Figure 3) and S'^P (Figure 4) were compared in order to determine other parameters with which the accuracy of determining the AUV position can be increased. The analysis of both charts led to the conclusion that the information about the presence or absence of land on a given bearing is very important. In view of the above, a variable was carried out for further research, which will count the places where the height of the land on a given bearing S_k, obtained on the basis of the representation of the surroundings of the S^P at point $P\ (\varphi, \lambda)$, is equal to zero (no land), and the height of the land S'_k, obtained on the basis of comparative representation at point P is non-zero (land). On this basis, the B coefficient was created, counting the number of pixels for which there is a situation in which:

$$S_k = 0\ AND\ S'_k\ != 0\ OR\ S_k\ != 0\ AND\ S'_k = 0$$

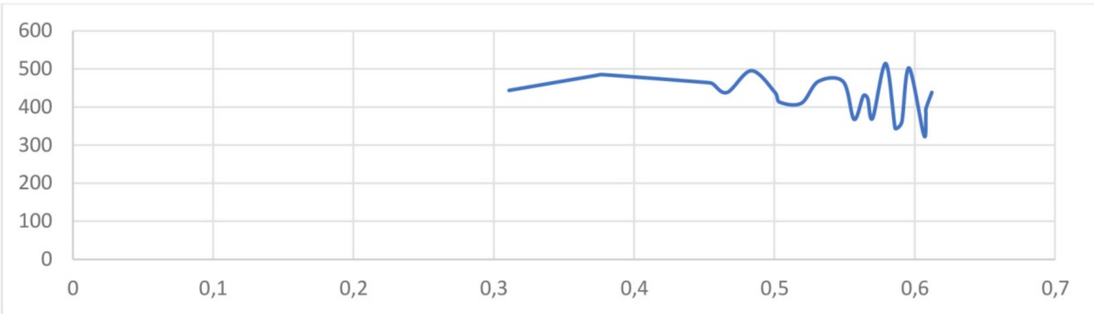


Figure 5 Dependence of the position determination error on the correlation coefficient for the point P

Source: own development

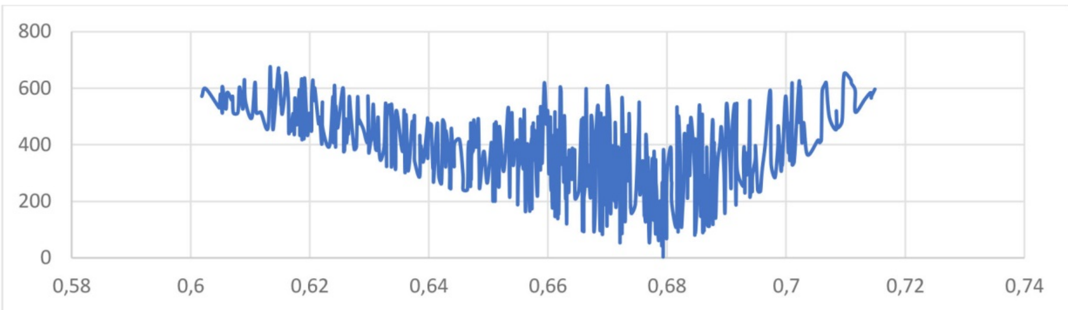


Figure 6 Dependence of the position determination error on the correlation coefficient for the point P

Source: own development

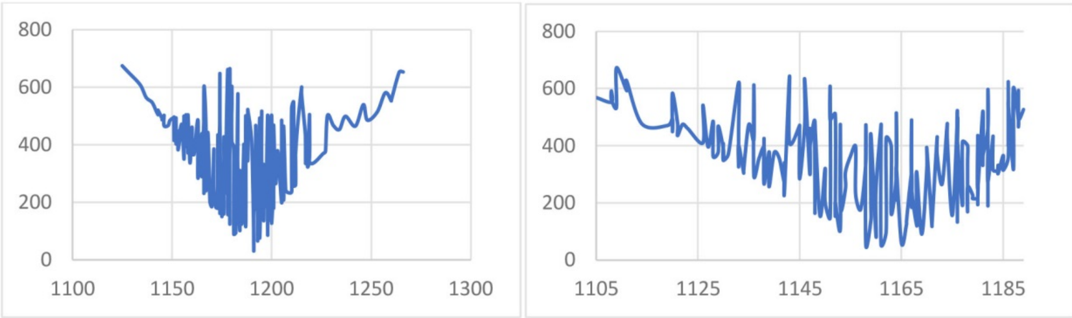


Figure 7 Dependence of the position determination error on the coefficient B

Source: own development

The obtained results turned out to be very irregular and did not improve the accuracy of determining the vehicle position. Therefore, it was decided to determine the similarity measure taking into account the influence of the similarity coefficient A and the coefficient B. To determine the influence of a particular coefficient on the final result, the parameter α was added, whose task was to determine the weight of each of the determined measures of similarity. It was decided to conduct research using two formulas:

$$C = \alpha \times A - (1 - \alpha) \times B \quad 11$$

$$C = \frac{\alpha \times A}{(1-\alpha) \times B} \quad 12)$$

where:

C – total similarity measure
A – similarity coefficient
B – percentage ratio

Moreover, in order to improve the quality of determining the correlation coefficient, the representation of the environment (Figure 8) was subjected to an approximation process using the Gauss algorithm (Figure 9).

Figure 8 Representation of the surroundings at point P

Source: own development

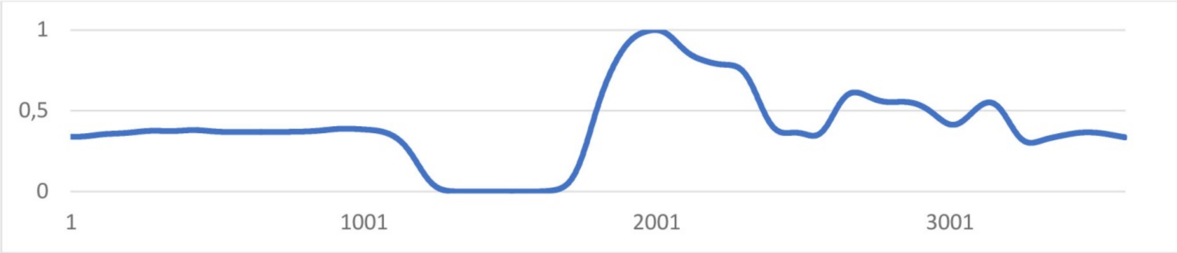


Figure 9 Representation of the environment at point P after approximation

Source: own development

Additionally, in order to smooth out the representation of the surroundings in places with large differences in height, it was transformed according to the following formula (Figure 10):

$$S_k = \log_{10}(100 \times S_k) \quad 13)$$

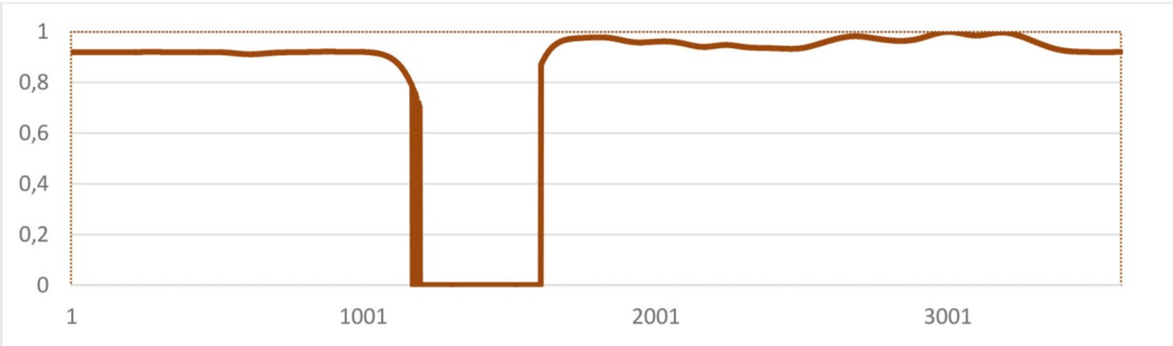


Figure 10 Representation of the environment at point P after transformation

Source: own development

The obtained representation is shown in Figure 11 shows a comparison of the representation of the environment after transformations and a map representation for a randomly selected point.

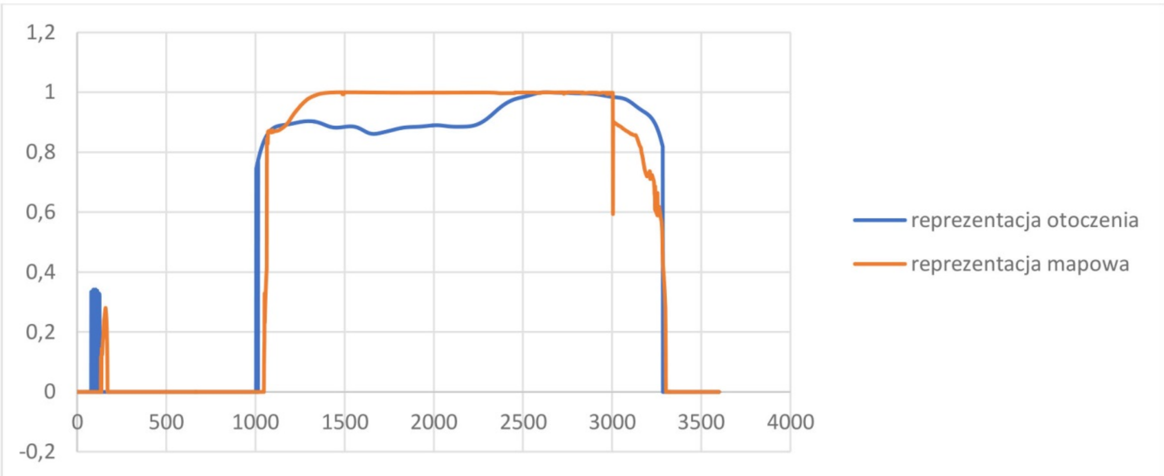


Figure 11 Comparison of the map representation and the representation of the surroundings

Source: own development

Then, tests were carried out for various values of the α parameter, thanks to which the influence of each coefficient on the overall similarity measure was determined. Table 1 shows the results for the selected top 15 measurement points (best results marked with yellow color).

Table 1 Dependence of position determination error on parameter α

Lp.	$\alpha = 0{,}9$		$\alpha = 0{,}5$		$\alpha = 0{,}2$	
	C	E	C	E	C	E
1	0,875	227	0,473	577	0,174	517
2	0,878	500	0,472	378	0,171	409
3	0,851	666	0,429	547	0,156	551
4	0,879	567	0,438	590	0,08	295
5	0,879	446	0,433	701	0,102	297
6	0,824	601	0,426	299	0,141	300
7	0,813	320	0,422	514	0,119	315
8	0,847	449	0,434	312	0,112	528
9	0,799	526	0,440	382	0,134	291
10	0,825	601	0,401	426	0,102	349
11	0,865	701	4,435	428	0,117	252
12	0,814	499	0,443	370	0,128	366
13	0,869	528	0,380	479	0,125	126
14	0,846	582	0,447	455	0,115	209
15	0,768	698	0,451	692	0,126	507

Source: own development

C - total similarity measure
E – position error

2. CONCLUSIONS

The conducted tests showed that the best accuracy was obtained for the parameter α 0.2. This means that the coefficient B is more important than the correlation coefficient. This situation is not surprising as the representation of the surroundings contains information about the height of the land on a given bearing, while it is not included in the map representation. However, the use of the sea map is not limited only to determining the areas where the land or sea will be visible. By analysing the map representations presented in this study, one can also notice the possibility of using additional information, such as the places where land ends or begins, which, thanks to appropriate transformations, can be used to improve the effectiveness of the proposed method.

The obtained results significantly differ from those presented in previous studies. At that time, the map representation was determined on the basis of the numerical land cover model, which is one of the most accurate models of the surroundings. However, the potential of the method presented in this study should be indicated of the surroundings. However, the potential of the method presented in this study should be indicated.

REFERENCES

[1] Heo, J., Kim, J. and Kwon, Y. Technology Development of Unmanned Underwater Vehicles (UUVs). Journal of Computer and Communications, 5, 28-35. 2017 DOI: 10.4236/jcc.2017.57003.

[2] Moussa, M.; Zahran, S.; Mostafa, M.; Moussa, A.; El-Sheimy, N.; Elhabiby, M. Optical and Mass Flow Sensors for Aiding Vehicle Navigation in GNSS Denied Environment. Sensors 2020, 20, 6567. https://doi.org/10.3390/s20226567

[3] Hożyń, S.; Zalewski, J. Shoreline Detection and Land Segmentation for Autonomous Surface Vehicle Navigation with the Use of an Optical System. *Sensors* 2020, *20*, 2799. https://doi.org/10.3390/s20102799

[4] Edelkamp S., Schrödl S. Heuristic Search, Theory and Applications 2012, Chapter 17 - Vehicle Navigation, Pages 737-757 https://doi.org/10.1016/B978-0-12-372512-7.00017-1

[5] T. Kashima, A. Asada and T. Ura, "The positioning system integrated LBL and SSBL using seafloor acoustic mirror transponder," 2013 IEEE International Underwater Technology Symposium (UT), 2013, pp. 1-4, doi: 10.1109/UT.2013.6519901.

[6] C. Zhuang, H. Zhao, C. Sun and W. Feng, "Detection and Classification of GNSS Signal Distortions Based on Quadratic Discriminant Analysis," in IEEE Access, vol. 8, pp. 25221-25236, 2020, doi: 10.1109/ACCESS.2020.2965617.

[7] Unsal, D., Demirbas, K., "Estimation of Deterministic and Stochastic IMU Error Parameters," Proceedings of IEEE/ION PLANS 2012, Myrtle Beach, South Carolina , April 2012, pp. 862-868.

METHODS OF INVENTORY MANAGEMENT IN SUPPLY CHAINS

Verena Dose
Institution Jade University of Applied Science, Faculty of Maritime and Logistics Studies
Elsfleth, Germany
E-mail: verena.dose@student.jade-hs.de

Aileen Wallenhorst
Institution Jade University of Applied Science, Faculty of Maritime and Logistics Studies
Elsfleth, Germany
E-mail: aileen.wallenhorst@icloud.com

Mark Černela
Institution Logoteam d.o.o.
Rijeka, Croatia
E-mail: cernela@logoteam.hr

Dražen Žgaljić
Institution University of Rijeka, Faculty of Maritime Studies
Rijeka, Croatia
E-mail: drazen.zgaljic@pfri.uniri.hr

UDK 658.78

Summary

Basic premise of methods of inventory management in supply chains encompasses ways of providing sustainable operations within the economy as an entity with management as its guiding factor. This paper is based on cumulative research done in order to provide insights about the policies which determine ways in which entities within an economy distribute their inventory in a most efficient, sustainable way ensuring prosperity and longevity of its business conduct. Focus has been put into the brief yet essential analysis of the tools used for improving accuracy of inventory management through depiction of their roles. Each tool represents a viable solution which is ultimately adjusted according to the needs of a company, and as a such, comes with its advantages and disadvantages. The paper did a theoretical and practical depiction of different inventory management methods that are represented in supply chains across all industries. Tools have been substantiated with simplified examples of strawberry warehousing and strawberry jam production to ensure overall intelligibility. Final remarks are made through analysis of the most commonly used policies inside the inventory management sphere.

Keywords: inventory management; policies; supply chain; sustainability

1. INTRODUCTION

This paper deals with the “methods of inventory management in supply chains.” The central role of inventories is to sustain operations within an economy. It is the management’s role to choose a policy that creates and distributes inventory most efficiently. Whatever the management chooses will determine how the company operates and which environmental factors influence them. This paper also portrays different inventory policies and reflects their advantages and disadvantages and what problems may arise in the form of the bullwhip effect. Tools were invented to improve the accuracy of inventory management and reduce mismanagement. Those tools are shortly explained, and their role is depicted. The future of inventory management is in the concept of PPS systems, which are explained and visualized.

To make the problem of inventory management more feasible following example is constructed:

A warehouse holding perishable products would like to streamline its inventory management. One of the problems they face is that on the one hand, if they have too many products in stock, the possibility rises that the goods may go bad, and the products need to be disposed of. This costs the additional warehouse money. On the other hand, if the warehouse has not enough products to distribute, it also costs money because it could not immediately meet the customers' demand. Due to this problem, the warehouse needs to find the balance in holding stock and provide a buffer between supply and demand. The previously mentioned will be visualized by the following theoretical excurses, and the example explains other inventory management challenges that come up.

An order is a binding request by the customer to the supplier to deliver certain goods and services on agreed terms and conditions. Following problems can occur if demand and order quantities do not match for technical or economic reasons:

- minimum order quantity
- quantity discounts
- fixed order costs of the customer
- storage costs of the buyer
- shortage costs of the buyer (Arnold & Furmans, 2009).

At the beginning of the month, the strawberry order reaches the warehouse. The number of strawberries has to meet the demand throughout the whole month. Assuming the demand is constant and has a continuous weight throughout the month. The left side of Figure 1 depicts the inventory stock after receiving the order at the beginning of the cycle. Once the inventory stock reduces to the reorder level, a new shipment of strawberries is triggered. The time from reorder point to minimum stock level is the time the supplier needs for the strawberry order to be delivered, also called lead time. Just after the shipment reaches the warehouse, the inventory stock is at the maximum level, and the cycle starts from the beginning.

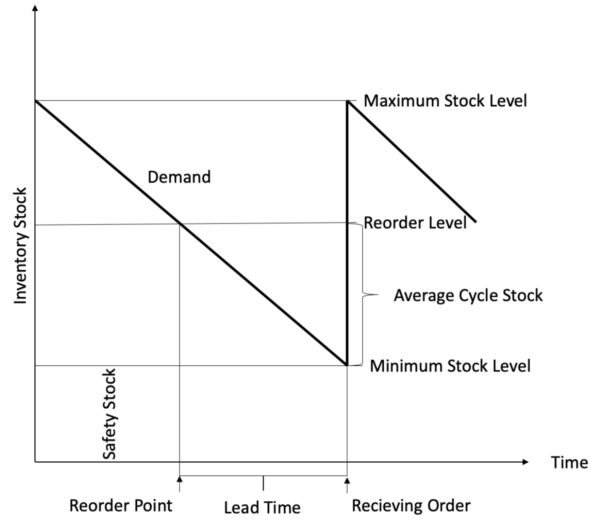


Figure 1 Stock between order and delivery

Source: Muckstadt & Sapra (2010)

1. INVENTORY MANAGEMENT, INVENTORY POLICIES AND MODELS

Inventory management describes the storage and management of products and articles in a warehouse (Koether, 2018). It is the tracking and controlling of a company's inventory as it is bought, manufactured, stored, and used. Therefore, inventory management regulates the entire flow of goods – from purchasing to sale – and ensures that the correct quantity of the right product is in the right place at the right time. In principle, inventory management's objective is to keep a company's inventories as low as possible, which leads to low warehousing costs. Nevertheless, the delivery service to the customer must be guaranteed without any bottlenecks. The aim is to optimize inventories early in the planning phase of production and transportation processes (Wild, 2018).

Depending on the products and goods, inventory can be classified into different types:

- finished goods, waiting for further transport,
- raw material, items that are purchased but not yet processed,
- Work-in-process (WIP), not fully completed, still needs some changes or further production,
- Maintenance/repair/operating (MRO) is necessary to keep machinery and processes productive (Unleashedsoftware.com, n.d.).

There are several different inventory policies in logistics, which are often embedded in Enterprise-Resource-Planning systems (ERP systems). These policies state when and what products must be ordered. For this, the four parameters are fundamental in the setting up of inventory control policies because they influence the policies:

- s is reorder point (ROP);
- S is target inventory level;
- q is order quantity;
- t is replenishment interval.

Furthermore, the inventory policies are either a continuous review policy or a periodic review policy. In a continuous review policy, the point of time of the next replenishment depends on the ROP. (s, q) policy and (s, S) policy are continuous policies. A periodic review policy is either a (t, q) policy or a (t, S) policy. At this, the period between two orders always stays the same (Willemain, 2019). The four different types and the policies' usage will be explained using an example in the following.

2.1. (s, q) policy

With the (s, q) policy, the time between two orders (t) is variable, and the order quantity (q) is fixed. In this model, the inventory level needs to be checked constantly. The instant the inventory drops to or below the order point (s), the order is placed. Thereby, the order size (q) is permanently fixed, which leads to warehouses that are not evenly full. Every order arrives to replenish inventory after a lead time. As a result, the lead time is assumed to be constant and known (Chileung Hui, 2014).

Due to the simple operation and the total control over the results, the (s, q) policy is commonly used. Furthermore, this continuous review policy leads to a shorter time between orders if there is a shortage. Another advantage is that it can consider demanding fluctuation, but one disadvantage in the inventory is that it needs to be controlled regularly (Ivanov & Schönberger, 2019).

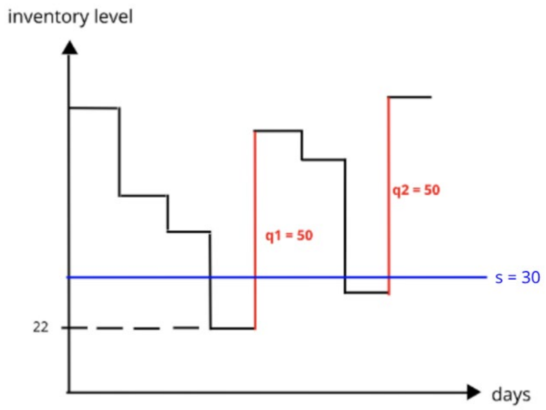


Figure 2 (s, q) policy – graphic

Source: own illustration

Assuming the warehouse, as mentioned before (1 Introduction), has a fixed quantity of 50 tons strawberries. The order point is at 30 tons to meet the constant demand. After checking the stock, the inventory level is only at 22 tons of strawberries. So, a reorder is executed. After replenishment, the stock now counts 72 tons. Then the strawberries are consumed for the production of strawberry jam. As soon as the inventory is again below 30 tons, a new reorder of 50 tons is triggered.

2.2. (s, S) policy

For the (s, S) policy or so-called (Min, Max) policy, the time between two orders (t) and the order quantity (q) between the minimum stock (s) and the maximum stock (S) are variable. Once the inventory drops to or below the minimum stock (s), the order for refilling the inventory up to the maximum (S) is placed (Brunaud, Lainez-Aguirre, Pinto, & Grossmann, 2018). This policy avoids an excessive inventory level and ensures that the company has the right items on hand to avoid shortages, but it can also lead to high storage costs (Ivanov & Schönberger, 2019).

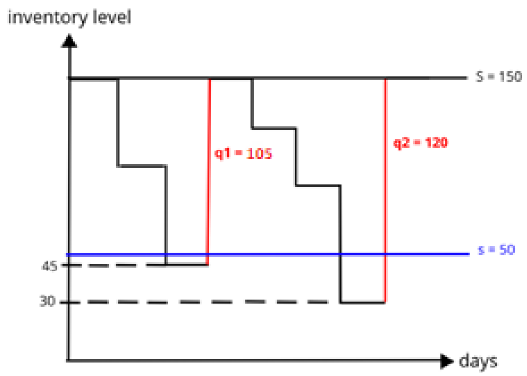


Figure 3 (s, S) policy – graphic

Source: own illustration

In this figure, the minimum stock is 50 tons, and the maximum is 150 tons of strawberries. After producing the strawberry jam, the stock is only at 45 tons, following a new shipment of 105 tons has to be made to reach the maximum of 150 tons again. As soon as the inventory level falls below the minimum of 50 tons, a new order of strawberries must be replenished to the maximum of 150 tons by a new order.

2.3. (t, q) policy

In the (t, q) policy, the time between two orders (t) and the order quantity (q) are both fixed. This policy is the simplest of all. The exact quantity of goods is always ordered at a specific time. Nevertheless, this also leads to the fact that this policy is very inflexible, and therefore it is used very seldom in companies. If a product is more requested than usual, it cannot be adjusted if a fluctuation in demand exists. Moreover, either understocking or overstocking occurs, which makes the policy very unattractive. Therefore, the (t, q) policy is only recommend under constant demand (Ivanov & Schönberger, 2019).

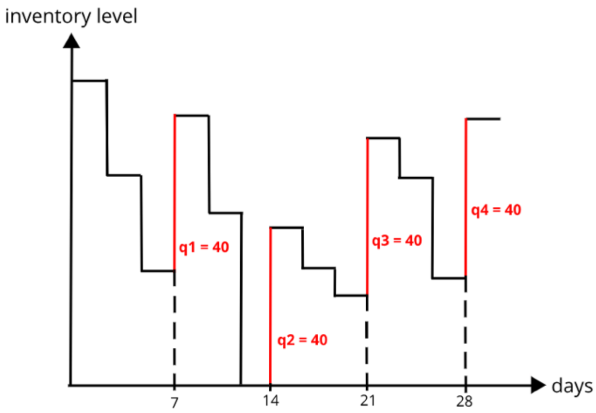


Figure 4 (t, q) policy – graphic

Source: own illustration

In this figure, the warehouse makes a new order of 40 tons of strawberries every week. Therefore, it does not matter if the stock of strawberries runs low and shortages occur, or the customers' demand was not high enough, and the stock is still high. This can be a significant disadvantage.

2.4. (t, S) policy

In the (t, S) policy, the time between two orders (t) is fixed, and the order quantity (q) is variable. Orders are made every T days. After measuring the inventory, the amount to refill the stock is computed (Dallery & Babai, 2005). On the one hand, this policy avoids any excess inventory. However, on the other hand, it is the most agile in responding to fluctuations in demand or lead time because it may take too long to fulfill the inventory, and it may imply high ordering costs due to small orders (Ivanov & Schönberger, 2019).

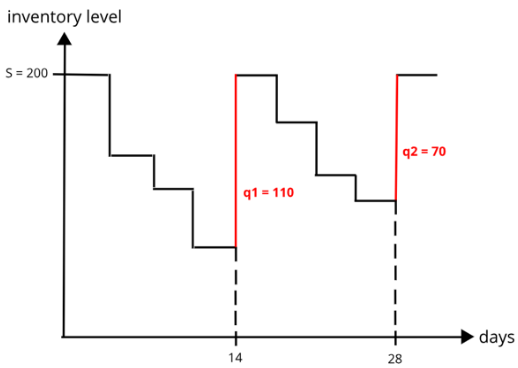


Figure 5 (t, S) policy – graphic

Source: own illustration

Considering that, after 14 days, the inventory stock is at 90 tons of strawberries, and the target inventory level is 200 tons of strawberries. This means that 110 tons need to be reordered to reach the desired quantity. After the next period, the inventory contains 130 tons of strawberries, so 70 tons need to be ordered to reach the target level of 200 tons.

Bullwhip effect

Every policy and method are invented to prevent the so-called bullwhip effect (Dolgui & Proth, 2010) or also whiplash effect. This phenomenon refers to an event by which orders placed with the supplier tend to fluctuate more than sales to the customer and thus deviate from demand. The deviation builds up in the upstream direction of the supply chain, i.e., the fluctuation increases towards the origin of the supply chain. This is illustrated below.

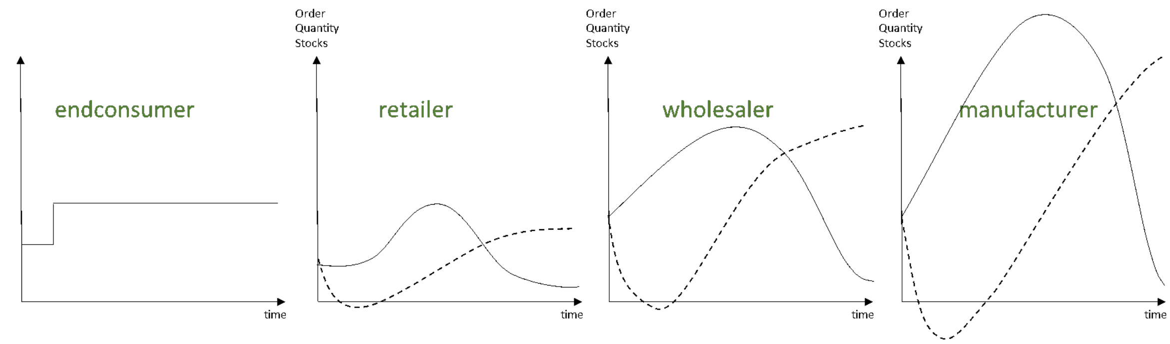


Figure 6 The bullwhip effect

Source: Zijm, Klumpp, Regattieri, & Heragu (2019)

The term takes on a central role in supply chain management in the context of risk management, as it highlights the need for integration and coordination along the supply chain. The bullwhip effect occurs as soon as an actor's demand forecast is based on observed demand.

A surge in demand is interpreted as a signal for high future demand, and the demand is excessively passed on to the supplier. For the example mentioned above, this would mean that if customers demand a larger quantity of strawberry jam than usual, the seller also orders more strawberry jam from his supplier. That leads to a chain reaction, which is reinforced by long delivery times of the supplier. Furthermore, batch orders from suppliers lead to orders being placed in larger quantities to reduce fixed order costs and take advantage of volume discounts or graduated prices. This means that the seller tends to order strawberry jam less frequently but at larger quantity discounts and save fixed order costs. Therefore, periods without orders are followed by periods with a large order quantity. Suppliers encourage these fluctuations by offering volume discounts. Depending on the forecasting method chosen, these aberrations in order levels can, in turn, lead to incorrect forecasts regarding future expected demand. Fears of shortages and supply shortages, i.e., irrational behavior in the form of "hoarding purchases," also generally induce buyers to plan order quantities generously. Sellers thus prefer to order large quantities of strawberry jam to avoid shortages accumulating at their customers. These surcharges, in turn, add up to large demand booms over several stages of the supply chain. However, if the shortage then fails to materialize, companies initially cover their requirements from the stocks of the strawberry jam they have built up, leading to an extension of the ordering intervals. Price fluctuations between the individual stages of the supply chain can also lead to fluctuations in order quantities.

To summarize this shortly, if a customer anticipates rising prices for strawberry jam, current demand will likely increase, and the customer will build up inventories that are not aligned with the current demand situation. As a result, the demand will be lower in the following periods, and thus the order intervals will be longer (Lee, Padmanabhan, & Whang, 1997). Other causes for the bullwhip effect can be an overreaction to backlogs, forecast errors, product promotions, inventory rationing, lead times, free return policies, and order cancelations (Dolgui & Proth, 2010).

2.5. Newsboy/Newsvendor model

The newsboy or newsvendor model is a stochastic inventory problem that concerns itself with stock demand to optimize its quantity to maximize the profit. The model does not consider holding costs and setup costs. At the beginning of the model, the stock is always empty. This model's conditions are that the selling price is higher than the production cost and bigger than the salvage value (Dolgui & Proth, 2010). A typical example here is the newspapers seller. The seller buys his paper in large quantities for 0.50€ per piece. One newspaper cost 2.50€. Therefore, the selling price is higher than the production cost and higher than the replacement value. This is because each sale generates a profit of 2.00€ for the newspaper seller. Of course, the seller should throw away his unsold newspapers at the end of the day instead of not serving customers, so the maximizing profit point would still have to be calculated at this point (DeMarle, 2019).

To come back to the constructed example, the warehouse distributes the strawberries to a retailer. This retailer's goal is to resell every strawberry he receives from the warehouse. Therefore, he sells the strawberries to other customers for a higher price. According to the model, the retailer achieves a bigger profit because he has no holding costs and no setup costs.

2.6. Finite-horizon model

The finite horizon model assumes that the demand is stochastic, and the inventory stock is checked in periods. The assumption being that at each period, there is still stock in the inventory. There is a relation between inventory costs and production costs/ordering costs. It seems to be a more theoretical approach since it is challenging to apply the analysis results to practice. The data is based on assumptions and will not work in real-life situations. Policies, which apply to stochastic demands and/or lead time are implemented to simulate the optimal solution. This model's opposite is the infinite horizon model, which is usually used in most theoretical concepts (Dolgui & Proth, 2010).

2.7. Echelon stock policy

In multilevel systems, especially in supply chains, there are two groups of ordering policies. One is the installation stock policy, and the other echelon stock policy or echelon base-stock policy.

For the first-mentioned policy, only stock information is local and used to manage the stock. For example, if the (t, q) and (s, S) policies are used, those policies could only work with the information of the current inventory level and their history.

The latter is the echelon (base-)stock policy. It works with more information than just what is locally available. The policy uses information from other stocks that are related to its own. Implementing this into the strawberry example would mean that the stocks of strawberries are listed, using the echelon stock policy and all other products needed to produce the strawberry jam, such as sugar. Also, it broadens the information horizon to the supply chain's general area and its history in inventory. For example, it is possible to track where the different products for producing the strawberry jam came from and when they have been stored in the warehouse. Because of the whole information background for the echelon stock policy, it is essential for supply chains. Especially if it concerns more than a single company, it is crucial for the data exchange between the supply chain parties.

It is possible to run more than one echelon – therefore, multilevel echelons are more efficient. The coordination of the decisions made in the different levels of the supply chain are further broken down into material requirements planning (MRP) and manufacturing resources planning (MRP) (Dolgui & Proth, 2010). The MRP concepts are essential for production planning and coordination and are presented in chapters 2.9 Material requirements planning (MRP) and 2.10 Manufacturing resources planning (MRP II).

2.8. PPS – Production planning systems

PPS systems are computer-supported production planning and control systems used for operational planning and control of the production process in an industrial plant/company. A company can utilize its resources like machines, employees, and materials more efficiently with a production planning tool (Voigt, Lackes, & Siepermann, 2018). Considering the dependence on the products or raw components of production, a company is limited in forecasting the demand for those elements. The actual need is directly connected to the finished product itself. MRP and MRP II are tools that are used for those components. Another feature closely connected to the demand requirements is the push and pull systems, which are further explained in the following (Rushton, Croucher, & Baker, 2014).

This tool is aimed at industrial companies with predominantly mechanical production, which keep a bill of materials - BOM (bill of materials or also called bill of requirements). Typical industry branches are mechanical engineering or the electrical industry, but not exclusively. For example, the chemical industry is also using PPS systems (Voigt, Lackes, & Siepermann, 2018).

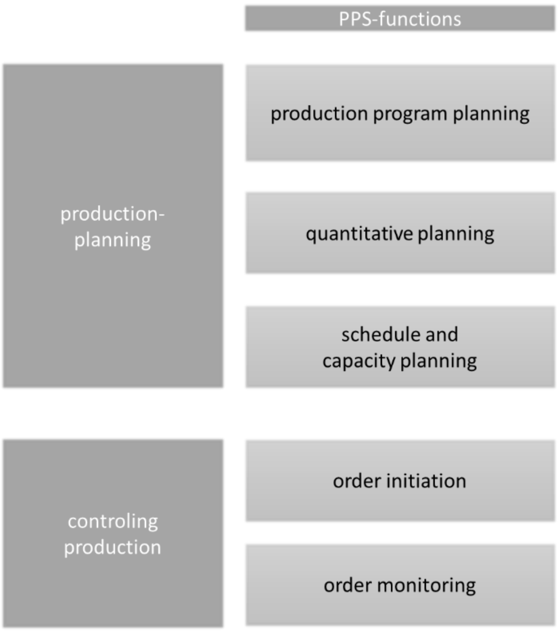


Figure 7 Basic concept of PPS systems

Source: own illustration based on information by B. Brucke

The system is roughly divided into the production planning process, where functions like production program planning, quantitative planning, and schedule and capacity planning occur. The other division is about production control, where order initiation begins and also order monitoring. In production planning, the local and temporal distribution of production is coordinated. Further, the optimum order quantities for the material requirements are determined to allocate and use the work processes sensibly. While in production control, the orders for production are coordinated. This includes allocating orders to the systems/machines and comparing production quantities and delivery dates.

Push principle

A push system is a traditional approach to inventory replenishment. This system is often used in mass production and is based on demand forecasting. It pushes the products through the production, hence the push principle. There is a central planning instance, and it uses the form of sliding logistics. As seen in Figure 8, the product is processed at the first point. Once it is ready there, it is transported to point 2, where it is further developed. With this principle, the product is passed through the entire production chain until it is finished. In this process, information flow and related material are only from the upstream and downstream points. This is illustrated in Figure 7 and is often used in MRP II, Optimized Production Technology (OPT), and to anticipate future demands (build-to-stock) (Rushton, Croucher, & Baker, 2014).

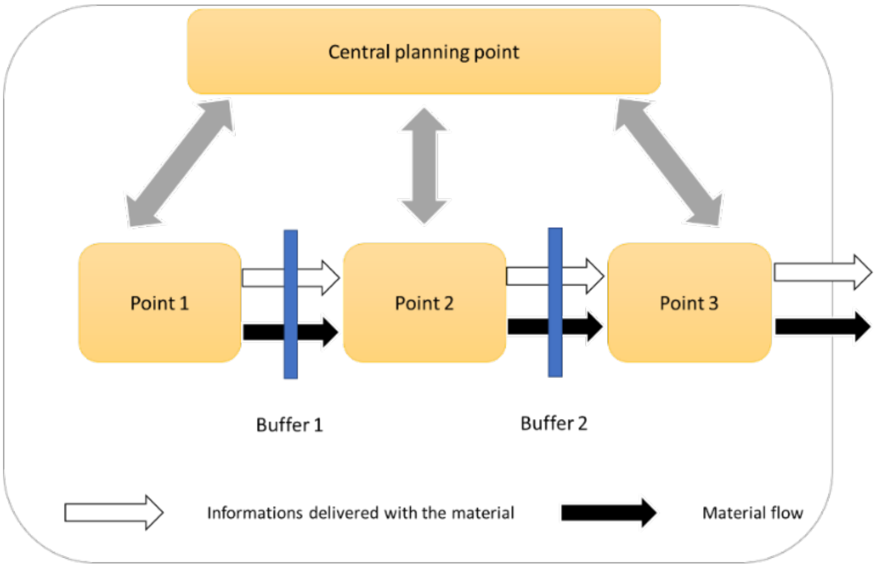


Figure 8 Push principle

Source: own illustration based on Rushton, Croucher, & Baker (2014)

It is necessary to enhance the constructed example from strawberry warehouse to producing strawberry jam to combine it with the push principle. Assuming there is a constant strawberry flow into production, strawberry jam is produced at all times, with no regard to the customer's demand.

Pull principle

The pull principle is a mission-synchronous procurement/production system (Just-in-Time-policy) or also called build-to-order. An approach for production control and also for the coordination of supply relationships. This principle is often used in the automotive industry. This is because it responds directly to customer demand, which triggers the pull.

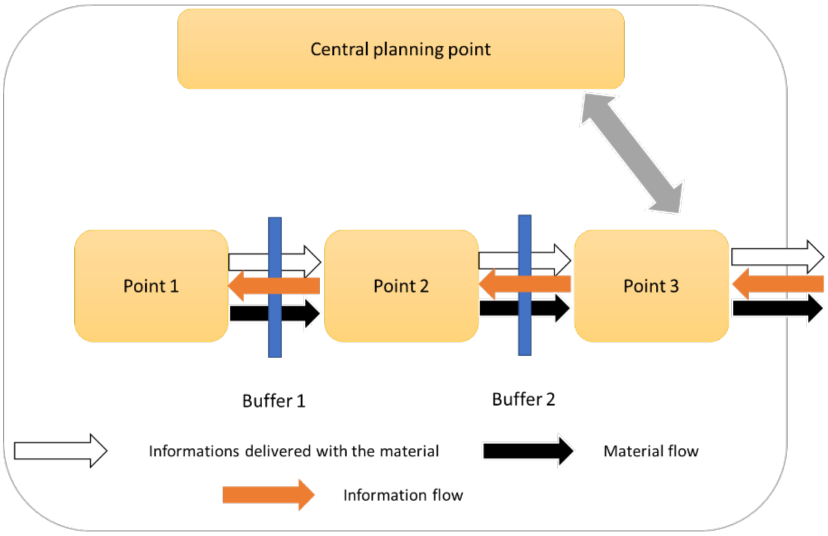


Figure 9 Pull principle

Source: own illustration based on Dolgui & Proth (2010)

In this case, the production of strawberry jam starts with the demand of the customer. Subsequently, the last point communicates the demand for strawberries downstream production chain.

Each point's communication is up-and downstream, but only the last point is communicating with the central planning point. This point is pulling the product through the production process based on the actual demand indicated by the information flow in Figure 9. This principle is commonly used in Just-in-Time production when the stock is at a certain level triggering replenishment. It is also used for the Kanban concept and the progress number concept because it can react very quickly to demand changes (Rushton, Croucher, & Baker, 2014).

By giving the customer control over the schedule, the pull principle leads to less waiting time from the customer's point of view. In addition, this principle increases fluctuations in demand and forces the corresponding company to develop flexible and adaptable processes.

In this case, the production of strawberry jam starts with the demand of the customer. Subsequently, the last point communicates the demand for strawberries downstream production chain.

2.9. Material requirements planning (MRP)

MRP or MRP I was the first installment of software for inventory management, back when the first computers were used to simplify production. After that, MRP evolved to MRP II and later into more complex systems as Advanced Planning Systems (APS) or the (holy grail) ERP systems, which will be further explained in chapter 2.11 Enterprise resource planning (ERP). MRP makes use of the push principle (Kummer, Grün, & Jammernegg, 2009).

MRP requires inventory balances and availabilities, production and purchasing times, and current order status, as well as forecasts and sales orders that determine the production schedule. With that information, an MRP calculates which parts and materials are required to produce an assembly or product and when these components are needed based on the final product's due date (Dolgui & Proth, 2010; Lackes & Siepermann, 2018).

To make use of the constructed example scenario. Compared to producing strawberry jam, one needs the ingredients from a recipe. The manufactory has to produce more than one ton as stated in the recipe; one needs to multiply the ingredients by the amount of strawberry jam that has to be produced. This list of constituent parts and the amount of those formulate the bill of requirements. This would allow one to purchase the necessary things needed to manufacture strawberry jam and avoid the possible waste of too much of one ingredient or the dilemma of not having enough of the ingredients, on the other hand. It is necessary to know the actual demand to match it to the forecast for this system's success (Rushton, Croucher, & Baker, 2014).

The advantages mentioned by Dolgui & Proth (2010) are that MRP reduces the inventory and number of late deliveries. It makes an adjustment to changes in the master production plan easier and better. MRP also improves productivity and makes better use of resources. The disadvantages are also mentioned as the following: errors of the past will most likely be repeated. This applies in particular to overestimated operation times. Those operation times are based on lot sizes that are not as big as the actual lot. The MRP has no scheduling function.

Although several disadvantages are mentioned in the literature, it is still an accepted production planning method. Nevertheless, since it is a computer-based tool, it cannot foresee special events like transport delays, the customers' varying demand, or defective machines in production. Additionally, MRP works based on known values of demand and lead time to produce order dates for the next release date of replenishments. The MRP approach can be modified, so the uncertainties for replenishment planning are possible. Safety stock is implemented to compromise the calculated lead times and between overstocking and stock-out while still keeping the overall cost (Dolgui & Proth, 2010).

2.10. Manufacturing resources planning (MRP II)

MRP II extends MRP with a capacity planning module. The planner is provided with information for maintenance management, sales orders, and procurement relevant information to balance available capacity and capacity requirements. Also, the system gets relevant information regarding cost accounting and implements that information for more accurate stock management. MRP II also includes the so-called business planning, with which, for example, sales targets or contribution margins can be included in the independent requirements planning. Because of the broader spectrum of information that feeds the MRP II, the company needs extensive computer power to integrate this tool for basically all production processes (Lackes & Siepermann, 2018; Rushton, Croucher, & Baker, 2014).

2.11. Enterprise resource planning (ERP)

Enterprise Resource Planning (ERP) refers to fully integrated business information systems for planning and controlling the entire company and using the available resources (personnel, capital, and operating resources) as efficiently as possible to optimize the operational process. Therefore, the business processes. Since Enterprise Resource Planning (ERP) was developed, many different companies' interest has steadily increased as they realized how versatile ERP systems are. Today, the ERP system is a crucial tool to manage the daily work in large and small companies. (Shengxu, 2020). It ties together many business processes like procurement, production, sales, master data management, human resources, finance, and accounting. All those are linked via a shared database. The company's size often determines the requirements for the functional areas of the use of ERP software, as accordingly, more or fewer departments must be combined in one system (Labarre, 2021). The most common ERP system are SAP (System Applications and Products in Data Processing), Oracle, and Microsoft Dynamics (Technologyadvice.com, 2021).

2.12. Lot sizing model

Determining lot sizes in manufacturing areas is the critical task of planning and controlling the production. It refers to the total quantity of an item or product that is ordered for manufacturing. With the assistance of the optimal lot size, production costs (warehousing costs, setup costs) are kept to a minimum. Thereby, the most cost-effective size is determined. Two aspects have to be considered. A company either produces only small lots, which leads to small warehousing costs and very high setup costs because the machinery needs to be changed after every product. Alternatively, the company produces large lots. This refers to higher inventory costs, but the setup costs are smaller (Schmidt, Münzberg, & Nyhuis, 2014).

For calculating the optimal lot size, the following formula, according to Andler, is used:

$$x_0 = \sqrt{\frac{2 * S * a}{h * p}}$$

x_0 = economic-optimal lot size

S = setup costs

a = planned demand for the article during the period

h = holding rate

p = production costs per unit (von Känel, 2019).

In order to explain this formula more clearly, the following example is made:

Assuming the demand for strawberry jam is 10,000 jars per year, and every order cost 100€. The cost per jar is 5€, and the holding rate is 10%. The following calculation is to be made:

$$x_0 = \sqrt{\frac{2 * 100€ * 10{,}000}{0{,}1 * 5€}}$$

$$x_0 = \sqrt{4{,}000{,}000}$$

Therefore, the optimal lot size is 2,000 jars per order.

$$x_0 = 2{,}000$$

That are 5 orders with 2,000 jars in a year.

3. CONCLUSION

The aim of the paper was to indulge into the sphere of inventory management and the commonly used tools which in turn enable most efficient and most sustainable solutions. Healthy looking and sustainably functioning inventory management peculiarly represents a gauge of company's balance sheet's financial health. The goal of every organization is to ensure optimal levels of inventory which suffices the demand from its users while keeping the warehousing costs and under inventory levels to a minimum because of their tendency to negatively affect financial figures. The paper illustrated different inventory management methods in a supply chain with the help of the constructed examples of a strawberry warehouse and the production of strawberry jam as a reference point. Due to various obstacles with order management, various tools in industries are used in order to ensure a smoother flowing business processes minimizing the risks of bull-whip effect occurrence. Therefore, several inventory policies were theoretically applied to the issue of inventory stock. In this context, the paper explains several essential terms of inventory and order management, including their importance to the whole process. Additional theoretical methods were described, which led to the broad field of PPS systems. Those systems are connected to the push and pull principles which are integrated in MRP I (Material requirements planning), MRP II (Manufacturing resource planning), and ERP (Enterprise resource planning) systems. All the methods, principles, and approaches mentioned above lead to the question of the optimal lot size, order frequency, and suitable safety stock. Generally speaking, good inventory management depends on many different factors, such as the different types of products, the size of the warehouse, the volume of production and ultimately the customer demand as well as many other factors which are to be considered in order for a company to be successful. Decision about the selection of right solution for a specific company is a daunting task given the fact about the multitude of factors which need to be incorporated into the equation. Securing a decent amount of company's budget is undoubtfully a starting point from which the development moves forward. Inventory challenges, types of needed integrations, ways of tracking items inside the system and quantity of users which will be enabled to access the system, their identification as well as their location represent are all factors which need to be considered prior to choosing of the suitable inventory management method, therefore each individual method will not probably suffice the demand a company requires while some overlapping similarities can definitely occur.

REFERENCES

[1] Arnold, D., & Furmans, K. (2009). Materialfluss in Logistiksystemen. Berlin: Springer.
[2] Brunaud, B., Lainez-Aguirre, J. M., Pinto, J., & Grossmann, I. (2018). Inventory Policies and Safety Stock Optimization for Supply Chain Planning. online: Wiley Online Library.
[3] Chileung Hui, P. (2014, September). An Optimization of (Q, r) Inventory Policy Based on Health Care Apparel Products with Compound Poisson Demands. Mathematical Problems in Engineering, pp. 1-2.
[4] Dallery, Y., & Babai, Z. (2005). Inventory Management: Forecast Based Approach vs. Standard Approach. Marrakech, Morocco.
[5] Dolgui, A., & Proth, J.-M. (2010). Supply Chain Engineering. London: Springer.
[6] ERP-systems.online. (n.d.). Retrieved April 2021, from https://www.erp-system.online
[7] Ivanov, D., & Schönberger, J. (2019). Inventory Management: A Decision-Oriented Introduction of the Creation of Value. Online: Research Gate.
[8] Koether, R. (2018). Distributionslogistik. Wiesbaden: Springer
[9] Kummer, S., Grün, O., & Jammernegg, W. (2009). Grundzüge der Beschaffung, Produktion und Logistik. München: Pearson Studium.
[10] Labarre, O. (2021, March 24). Investopedia.com. Retrieved April 2021, from https://www.investopedia.com/terms/e/erp.asp
[11] Lackes, P. D., & Siepermann, D. M. (2018, 02 19). Gabler Wirtschaftslexikon. Retrieved from https://wirtschaftslexikon.gabler.de/definition/mrp-39273/version-262686
[12] Lee, H. L., Padmanabhan, V., & Whang, S. (1997, April). Information Distortion in a Supply Chain: The Bullwhip Effect. Management Science Vol. 43 No. 4, pp. 546-558.
[13] Muckstadt, J. A., & Sapra, A. (2010). Principles of Inventory Management. New York, Heidelberg, Dordrecht, London: Springer.
[14] Rushton, A., Croucher, P., & Baker, P. (2014). Handbook of Logistics & Distribution Management (5. ed.). London, Philadephia, New Dehli: Kogan Page.
[15] Schmidt, M., Münzberg, B., & Nyhuis, P. (2014). Determining lot sizes in production areas - exact calculations versus research-based estimation. 3rd CIRP Global Web Conference (pp. 143-148). Germany: Elsevier.
[16] Shengxu, L. (2020). Research on ERP Software Course Optimization Based on Big Data Technology. Journal of Physics: Conference Series (pp. 2-3). China: IOP Publishing.
[17] Technologyadvice.com. (2021, April 07). Retrieved April 2021, from https://technologyadvice.com/erp/
[18] Unleashedsoftware.com. (n.d.). Retrieved from https://www.unleashedsoftware.com/inventory-management-guide
[19] Voigt, P. D.-I., Lackes, P. D., & Siepermann, D. M. (2018, 02 19). Gabler Wirtschaftslexikon. Retrieved from https://wirtschaftslexikon.gabler.de/definition/pps-system-42854/version-266195
[20] von Känel, S. (2019). Arbeitsbuch zu Betriebswirtschaftslehre - Eine Einführung. Dresden, Germany: Springer.
[21] Wild, T. (2018). Best Practice in Inventory Management (Vol. 3. Edition). Routledge.
[22] Willemain, T. (2019, October). Smartcorp.com. Retrieved from https://smartcorp.com/inventory-control/inventory-control-policies-software/
[23] Zijm, H., Klumpp, M., Regattieri, A., & Heragu, S. (2019). Operations, Logistics and Supply Chain Management. Cham, Switzerland: Springer.

A HUMAN IN FOCUS OF MARINE WASTE POLLUTION

Dorotea Žic
Polytechnic of Rijeka
Rijeka, Croatia
E-mail: dorotea.zic@veleri.hr

UDK 504.61:656.61

Summary

Waste pollution, which mostly ends up in soil, lakes, oceans and seas, has become a problem on a global level, precisely as a dangerous form of pollution due to its harmful properties. Although the amount of waste is constantly increasing, humans are not yet fully aware of how disposing of waste in the marine environment impairs their own health and the health of animals, as well as the survival of plants. Waste toxicity actually threatens all living and non-living organisms. Most of the waste found in the wild is subject to different degradation processes including shredding, to be subsequently introduced into the food chain by organisms such as fish and plants, and as such harmfully restored to human bodies. Thus, humans are realized in the focus of this continuous circle of waste, which was initiated by our own actions and points to the inevitable paradigm shift – the humane challenge as the dominant need for a changed human thinking, behaviour and actions in today's communication and technological world. In this paper, special emphasis has been placed on waste in the sea as seen in the focus of human beings, with particular emphasis on the toxicity of waste, as well as its impact on the marine environment and the entire ecosystem and thus on the health of all living beings on our planet.

Keywords: sea, oceans, waste pollution, marine waste, paradigm shift of human thinking, behaviour and action

1. INTRODUCTION

The issue of marine waste has imposed itself as one of the global social, economic, environmental and aesthetic challenges, which are part of the complex phenomenon of marine pollution. A holistic approach should certainly be applied by supporting action at all levels by raising public awareness, from the local to the international and global level. It is necessary to acquire and deepen knowledge in the field of oceanography and marine sciences - marine biology, biotechnology, as well as knowledge and public awareness about pollution by nanoplastics and microplastics and its effects on the environment, in order to protect marine ecosystems and the sea. Further research on the spread of marine waste in the oceans and seas should certainly be carried out, crucial for a better understanding of the extent of marine pollution.

The paper seeks to highlight and enhance the shared vision of healthier, more productive and resilient oceans and seas, in promoting biodiversity and protecting against marine waste in their protected areas, promoting the social well-being and prosperity of citizens and every single individual, now and for future generations, in order to identify, remove, classify and recycle all types of collected marine waste into valuable raw materials while strengthening economic growth. The necessity of raising awareness for the purpose of further implementation of citizen interventions is emphasized, because direct and indirect human activities have affected the marine environment, causing numerous problems such as global warming and acidification of oceans at the global level and overfishing and pollution at the local one. Therefore, addressing the cumulative effects of these activities is necessary to preserve the marine environment for our present and future generations. Undoubtedly, the support of research in science and technology is important in order to solve these environmental problems.

2. MARINE WASTE IN OCEANS AND SEAS – A GLOBAL CHALLENGE

The seas and oceans are important for life on Earth, because they control the climate, participate in biogeochemical cycles and the flow of energy in the biosphere [1], are a source of food and many resources and are important for various human activities at sea and on land. The world's oceans and seas are an uninterrupted body of water, whose good state of the environment is key to ensuring its resilience and the continued provision of ecosystem services such as CO_2 absorption and oxygen production.

Marine waste is: any persistent, manufactured or processed solid material disposed of or abandoned in the marine environment and coastal area. It occurs exclusively due to traffic, tourism and other human activities on land or at sea, or due to shortcomings in the attitude of waste management. Marine waste is a global challenge because it poses a threat to the future of humanity and the performance of various marine and coastal activities in general. The waste in the oceans and seas mostly comes from land-based activities (80%), but also from activities at sea - maritime transport 20%, where there has been a significant increase in traffic [2] of increasingly large ships and other vessels.

All over the world, large amounts of waste continue to be discharged directly into the sea, to be carried over long distances by sea currents and winds, thus affecting areas and sectors that are far from its source which is therefore not considered responsible for its production. There are many sources of marine waste pollution, such as pollution of watercourses and rivers, poor management of waste collection (sewage and waste from unregulated landfills), rainwater and swollen rivers as well as natural phenomena such as floods or rains that wash waste from urban areas towards the sea, dumping waste into the environment or various accidents, maritime transport and fishing, tourism and other activities [3, 4]. It is human negligence and improper waste disposal that are the most common causes of pollution, including, for example: discharges from industry, pharmaceutical waste, pesticides and sewage; expansion of industrialized agriculture with increased use of chemical fertilizers; poor onshore waste management that generates 27% of marine waste from fisheries and aquaculture, according to the Joint Research Centre, and many others [4].

Research work on the spread of marine waste in the oceans and seas is crucial for a better understanding of the extent of marine pollution. The consequences of the spread of marine waste around the world and its repercussions on people and the environment are as follows [4, 5]:

- Marine waste found on beaches, coasts, coastal areas and on the water surface actually masks the occurrence of much more widespread pollution in the water column as well as on the seabed. It is estimated that 70% of marine waste in the sea ends up on the seabed and that the total mass of waste floating on the surface makes up only 1% of the plastic present in the oceans. As visible waste accumulated on the surface it represents only a small portion of the problem compared to that in the water column and further on to the large ocean furrows (e.g. Marian Furrow - waste found at depths greater than 10,000 meters).
- The issue of marine waste is largely related to poor onshore waste management [6], for example in watercourses and rivers, poor wastewater management, above-ground illegal landfills near watercourses, occurrences such as waste dumping in the environment and water runoff after storms and rains.
- Diffuse pollution, such as treated or untreated wastewater that may contain chemicals or pharmaceutical waste, or rainwater or water generated by runoff from urban or agricultural areas. Thus, for example, the release of nitrogen and phosphorus threatens the marine environment due to eutrophication [1] caused by high concentrations of nutrients, which can eventually lead to sea floor hypoxia and an increase in "dead areas" (whose number has increased tenfold since the middle of the last century), contribute to the appearance of green and red algae, and significantly contaminate marine flora and fauna;

- The presence of marine waste poses a serious threat to the resilience and productivity of marine ecosystems, especially the most vulnerable ones, which are already exposed to many cumulative pressures, such as climate change [1, 7, 8, 9], pollution, illegal, unregistered and unregulated fishing, overfishing and increased activities such as maritime transport and tourism.
- Increased pressures on marine ecosystems lead to a reduction in biodiversity [7] and suffocation of benthic organisms and increase the risk of disease spread due to the presence of pathogens caused by the accumulation of marine waste on the seabed. Almost 80% of Europe's marine biodiversity is located in the outermost regions and overseas countries and territories where their economies are largely based on fisheries and tourism.
- Negative morphological effects caused by accumulations of waste, especially around small remote islands and coastal areas.
- Ocean acidification caused by increased absorption of carbon dioxide into the sea. Such acidity of the sea and oceans destroys coral reefs, hinders the development of shellfish, dissolves microorganisms that contain calcium in the basis of the marine food web and increases the toxicity of some pollutants.
- Marine waste represents a surface to which many organisms and bacteria can attach, which facilitates the introduction of invasive species that can alter the balance of marine ecosystems and makes it possible for marine waste bacteria to be exchanged for food and ingested by marine fauna.
- Negative impact through the sewerage network poses a risk to aquaculture and oyster farmers, as the quality of their products may be compromised by the presence of viruses and bacteria such as norovirus, which may lead to a temporary ban on the sale and distribution of their products if they are no longer suitable for human consumption.
- The seabed is threatened by mechanized trawling, oil and gas exploration, excavators, and planned deep submarine metal mining.
- According to the latest scientific research, the level of plastic pollution in the oceans is greatly underestimated even at the time of its increasing actualization. Sea currents can transport this waste to the surface in accumulation zones, but it is estimated that there are up to 1.9 million fragments of microplastics per square meter in depth in the focal points on the seabed and underwater slopes. Sea currents carry marine waste to all parts of these seas around the world and particularly endanger small isolated islands and coastal areas because they are unable to protect themselves effectively from it. The occurrence of condensation over the ocean allows pollution of areas that were previously considered intact. This partly explains how traces of microplastics have been found in snow in the Alps and the Arctic.
- It is estimated that about 730 tons of waste is discharged into the Mediterranean Sea every day, and every year 11,200 tons of plastic released into the environment end up in the Mediterranean Sea according to the report of the World Wide Fund for Nature (WWF) from June 2019. A quantity of plastic waste equal to that which would be unloaded by 66,000 garbage trucks is released into the Mediterranean Sea every year. Microplastics in the Mediterranean reach a record concentration of 1.25 million fragments per km^2. As small fragments make up about 90% of the total amount of plastic floating in the Mediterranean Sea, there are about 280 billion fragments of floating microplastics. Thus, the average consumer of Mediterranean shellfish swallows 11,000 fragments of plastic a year. That is why the Mediterranean is one of the most polluted seas in the world.
- Marine waste poses a serious threat to many marine animal species, but also to other animal species such as seabirds, some of which are already endangered or threatened with extinction. Due to marine waste, among other reasons, degradation of marine and coastal ecosystems occurs and poses a risk to all economic operators operating in coastal areas and therefore endangers the sustainability, continuity and attractiveness of coastal communities due to the risk of strangulation, suffocation, ingestion, injury and contamination.

- Tobacco waste is the most widespread type of waste in the world according to the World Health Organization (WHO), and cigarette butts are the first among the ten most frequently collected items in international beach cleaning actions according to the American ocean conservation organization NGO "Ocean Conservancy". It has been found that it takes 12 years to decompose a single cigarette butt containing nearly 4,000 chemicals, and each cigarette butt that ends up in the oceans and rivers pollutes 500 litres of water.
- Spread of harmful algae flowers to previously intact areas of depth due to expanded industrialized agriculture using chemical fertilizers.
- Global decline in fish stocks caused by discharges from industry, pharmaceutical waste, pesticides and sewage.
- According to estimates, marine waste causes a loss of revenue of 1 to 5% of the fishing industry.
- Negative impact of the spread of marine waste worldwide on the third developing countries and in particular coastal communities that depend on fishing and do not necessarily have the capacity or means to effectively protect themselves from such waste.
- New waves of marine pollution, especially due to the use of disposable products such as surgical masks, gloves and other protective means used for these purposes during the crisis caused by the COVID-19 disease.
- High costs for the disposal of marine waste are very often covered, but this is not the case with labour costs, costs arising from the lack of space on vessels and costs associated with damage to fishing equipment.

In order to reduce marine waste as well as to respond to its feedback impact on activities at sea (fisheries, etc.) and on land, it is necessary to act as follows [5]:

- take into account the life cycle of waste from the initial to the final phase as well as its connection with the hydrological cycle (either natural or through wastewater - diffuse pollution);
- better understand these phenomena in order to adopt a more effective legislative framework, approach the waste life cycle holistically and globally;
- implement a constructive action plan for the management of marine waste on land, especially against waste disposal along watercourses in catchment areas, especially microplastics and nanoplastics, because the prevention of pollution from land-based sources is crucial;
- develop a true circular economy in the fisheries and aquaculture sector and launch coordinated waste collection in watercourses, estuaries and at sea;
- determine the networks of locations for the collection and acceptance of marine waste, i.e. locations for the development of reception centres for marine waste in fishing ports and discharging points;
- develop models for reducing and preventing waste in the sea and marine ecosystems as well as models for reuse and treatment of plastic waste, and the like.

The European Union seeks to promote an integrated approach to marine activities, including the issue of marine waste that needs to be addressed more actively by taking greater account of the spatial dimension of maritime and coastal activities. The marine waste disposal campaigns contribute to the reduction of marine waste pollution, to the benefit of the whole community, society and the EU. Efforts are being made to involve these coastal communities and fishermen in the collection of marine waste in order to take into account the special characteristics of local communities, as fishing activities take place mainly in coastal areas. Without an appropriate compensation mechanism for their efforts, fishermen and aquaculture farmers cannot be expected to collect marine waste. It is estimated that up to 80% of fishermen would be willing to participate in marine waste collection programmes if support mechanisms were established. [4]

Although little contribution has been made to solving this problem globally, fishermen and aquaculture breeders have long played an active and proactive role in contributing to cleaner seas. The fisheries sector has for some time been the first line of defence against pollution caused by marine waste. Fishermen and fishermen's associations are already working on the collection of marine waste and that there are solutions for its use, especially when it comes to fishing waste.

The best way to reduce the amount of marine plastic waste is to reduce and avoid its production and focus on recycling and reuse of materials and products. Obsolete materials and tools that could become waste need to be recycled and urgent economic support is needed to have their materials and tools (currently only 1.5% of fishing gear is recycled) collected, recycled and repaired [4]. In particular, the fisheries sector could benefit from new economic opportunities by participating in a circular economy based on smart design, research and innovation.

While envisaging for the blue economy to double by 2030, it represents a real opportunity for the sustainable development of maritime and coastal activities. In particular, because it is based on the development of infrastructure with positive effects, such as artificial reefs and other innovations that promote the effect of reefs and reserves, which can contribute to the restoration of ecosystems. Only clean, healthy, productive and biologically diverse coastal and marine environment can meet the long-term needs of people in general, and marine and coastal activities in particular (the sector of fisheries, fishermen, shellfish farmers and fishing communities).

3. HUMAN AWARENESS AND RESPONSIBILITY FOR THE CREATION AND DISCHARGE OF MARINE WASTE AND MARINE POLLUTION

Human activity that creates and releases unwanted waste into the air, water and land is a challenge [10] for all humankind as it is becoming the greatest cause of disease of all living beings on the planet [6]. Therefore, efforts are being made to achieve effective national, regional and international marine pollution control programmes that are adequately funded and supported by strong implementation, as such monitoring and control is necessary to monitor progress.

It is human negligence and improper waste disposal that are the most common causes of pollution, including, for example: discharges from industry, pharmaceutical waste, pesticides and sewage; expansion of industrialized agriculture with increased use of chemical fertilizers; poor onshore waste management that generates 27% of marine waste from fisheries and aquaculture, according to the Joint Research Centre, and many others. [4]

The damages resulting from this reckless, short-sighted and unsustainable exploitation of terrestrial resources of the sea are [5]:

- Marine ecosystems are being threatened.
- Atmospheric oxygen production is being hampered.
- Threats to human health are great and growing, and are still not fully understood.
- Economic costs that are continuously being estimated.

Our excessive pressure on the world’s seas, coastal development and climate changes have put at risk the biodiversity and stability of many marine ecosystems. Any change in the marine and coastal ecosystems could weaken their role of climate regulators.

Precisely because of the knowledge of the interconnectedness and codependency between humans and the sea, it is the mission of the leading people of all humankind, with emphasis on every single individual, to ensure good health of marine and coastal ecosystems as well as the sea by changing their own awareness, behaviour and actions. This is very important because marine and coastal ecosystems and the sea have an important role in the climate balance and in ensuring the development of marine and coastal activities in order to ensure the health of every human and living being on the planet.

By protecting U.S. environmental and economic interests across the world's oceans, the EPA (U.S. Environmental Protection Agency) is helping to shape U.S. government views on international marine pollution issues. EPA works with partners in U.S. government agencies, NGOs, various foreign countries, industry, and other entities to secure international decisions and management of marine pollution issues. The mission of the EPA is: "To protect human health and safeguad the natural environment - air, water and land – upon which life depends." [11]

The objectives for achieving the well-being of the seas and oceans are to [5]:

(1) Increase the knowledge about the sources of pollution, pollution levels in many areas of the sea, the size of populations at risk, the extent of plant, animal and human exposures and the magnitude of impacts on the health of ecosystems and all beings on the planet.

(2) Widely examine the known and potential impacts of ocean and sea pollution on human health.

(3) Propose priorities for interventions to control and prevent marine pollution and protect human health through policymakers, government leaders, international organisations, civil society and the global public.

In working and partnering with businesses, organizations and governments using the latest technological and social innovations, Conservation International aims to protect the ocean globally. The planetary goals are "to actively conserve preserve 30% of the global ocean by changing area-based measures and ensuret that at least 75 percent of seafood globally is produced using socially responsible and environmentally sustainable methods by 2030." [12]

The EU framework for the protection of the marine environment is a comprehensive and ambitious one, but there are still problems such as eutrophication, underwater noise, plastic waste, unsustainable fishing, pollutants and other types of pollution. Achieving the general objective of "good environmental status" is determined on the following descriptors: biodiversity, fishing, eutrophication, pollutants, waste and underwater noise. According to the EU Directive, one of the main legislative acts that protect and preserve marine biodiversity and marine habitats, its members seek to strengthen measures and act decisively on the basis of the following adopted strategies [13, 14, 15, 16]:

- Intensify measures to protect the seas and oceans based on the Strategy for Clean, Healthy and Productive Seas coordinated at the regional level, where members must achieve the state of the environment in their territorial waters to which they were legally obliged.
- Urgent and harmonized protection and restoration measures based on the new EU Biodiversity Strategy and the Farm to Fork Strategy by 2030 and other elements of the European Green Agenda. This could contribute to the goal of achieving a lower pollution rate at sea. The protection of the EU's seas and oceans is an important part of Europe's green agenda, so that fishermen can continue to ensure healthy and sustainable seafood in future. Protection should certainly be included in all policy areas.
- Decisive and consistent action based on Strategies for Sustainable Chemistry to avoid changing the general physical and chemical properties of the sea. EU regulations governing chemicals have led to a reduction in pollutants.
- Resolute and consistent action based on the Smart and Sustainable Development Strategy, according to which marine ecosystems would still have a chance to recover if a sustainable balance is established between the way the seas are used and the human impact on the marine environment. Thus, for example, in the area of sustainable fisheries, although some progress has been made, even greater efforts are needed to stop irresponsible marine pollution.
- Irrespective of decisive and consistent action, the uneven state of Europe's seas is pointed out in the Marine Strategy Framework Directive. Although the EU's Common Fisheries Policy applies, the situation is worse in the Mediterranean compared to fish caught from the north-east Atlantic in terms of healthy stocks. Almost half of Europe's coastal waters are undergoing intensive eutrophication.

In accordance with the Commission's Better Regulation agenda until mid-2023, the revision of this directive will analyze in detail the achievements and problems related to environmental protection. A revision of the Common Fisheries Policy will also be carried out. Based on these parallel audits, possible changes will be proposed by 2023. The European Environment Agency's "Marine Communication II" report, which the Commission takes into account in its audit, states that past and sometimes current use of European seas leads to changes in the structure of marine species and habitats, as well as changes in general physical and chemical properties of the sea. Solutions are proposed that would enable the seas in the EU to become clean, healthy and productive according to the Mission area: Healthy oceans, seas, coastal and inland waters. [17] Ecosystem-based management is offered as the main solution, although it has been found that in some areas there are signs of recovery of marine ecosystems as a result of strong and often long-term efforts to mitigate the impact of pollution.

Since the sea knows no borders, the polluted state of marine environment requires the acquisition of knowledge [18], the development of skills and abilities, and personal and collective responsibility of everyone on the planet as well as the awareness of the ways the sea affects humans and vice versa. Global and European actions have a major influence in terms of protecting our common good [19, 20] and not allowing waste in our seas to accumulate without restrictions.

Leaders, scientists, innovators, creators, research centres, recycling companies, marine scientists, robotics experts, governmental and non-governmental organisations, communities, associations, all special ingenious individuals in groups and professional teams and beyond who recognize the severity of ocean and sea pollution as well its growing dangers, motivate and engage citizens, residents, tourists and society as a whole [18, 21, 22], They are taking bold, evidence-based actions to stop pollution at source; promote numerous projects, new solutions for the removal and recycling of marine waste, developed and integrated replicated and automated technologies in cooperation with renewable energy [18, 23, 24] and the implementation of a profitable combination of good practice that strengthens cross-border cooperation between countries. This is an attempt to sensitize civil society and the global public to protect valuable resources such as the ocean and sea, all with the aim of protecting the environment, marine conditions and the coastal system, which inevitably protects animal and human health on the planet. Raising citizens' awareness and promoting international cooperation, in order to achieve clean oceans and seas for future generations, recognizes the importance of the problem and the exchange of best practices and the promotion of innovative solutions through joint efforts.

Global pollution of the seas and oceans requires a coordinated and collective response to achieve effective global cooperation and associations and joint action, which would connect different nations from different living conditions [25]. Such a feasible joint effort could solve the problem as a whole only through a global approach with radical changes that would affect almost every aspect of human life on this planet [26].

4. CONCLUSION

Just like the oceans and seas, including the Adriatic Sea and all water surfaces, have always served humanity , let humanity all serve them in return in an adequate and constructive way. Thanks to changes in our consciousness, attitudes and behaviour, the path is made for future generations to inherit clean and healthy oceans and seas. Efforts are needed to raise the awareness of every single individual in the interconnection of all humanity for the salvation and well-being of all living beings on the planet.

Thanks to all scientists, experts, innovators, creators, governmental and non-governmental organizations, communities, associations, all special ingenious individuals in groups and professional teams and beyond for implementing projects, constructive actions and concrete procedures and public participation, education and informing the general public with the aim of changing the human consciousness, attitudes and behaviour. Thanks to all those who bravely and fearlessly even lost their lives on that path of necessary change.

REFERENCES

[1] Clark C. M. Grimm, N.B., Galloway, J.N. and others: Biogeochemical Cycles, National Climate Assessment, The National Climate Assessment summarizes the impacts of climate change on the United States, now and in the future. A team of more than 300 experts guided by a 60-member Federal Advisory Committee produced the report, which was extensively reviewed by the public and experts, including federal agencies and a panel of the National Academy of Sciences. National Climate Assessment. U.S. Global Change Research Program 1800 G Street, NW, Suite 9100, Washington, D.C. 20006 USA, 2014. https://nca2014.globalchange.gov/report/sectors/biogeochemical-cycles

[2] Strateška studija utjecaja na okoliš, Strategije prometnog razvoja Republike Hrvatske 2017.-2030., Ministarstvo mora, prometa i infrastructure, Zagreb, IRES EKOLOGIJA d.o.o. za zaštitu prirode i okoliša, Zagreb, normi ISO 9001 - broj certifikata: CRO20168Q , normi ISO 14001- broj certifikata: CRO19455E https://mmpi.gov.hr/UserDocsImages/arhiva/1.%20SPUO%20Strategije%20prometnog%20razvoja%20Republike%20Hrvatske%202017.%20-%202030.%2027-09_17.pdf

[3] Črnjar, M.: „Ekonomija i zaštita okoliša", Školska knjiga Rijeka, Glosa, Rijeka, 1997. (ISBN 953-0-30329-7)

[4] Report on the impact on fisheries of marine waste, Izvješće o utjecaju morskog otpada na ribarstvo, Committee on Fisheries, Odbor za ribarstvo, Prijedlog rezolucije europskog parlamenta o utjecaju morskog otpada na ribarstvo, 2021. Procedure: 2019/2160(INI) Document stages in plenary Document selected: A9-0030/2021, 2021 https://www.europarl.europa.eu/doceo/document/A-9-2021-0030_EN.html; https://www.europarl.europa.eu/doceo/document/A-9-2021-0030_HR.html

[5] Landrigan, P. J,. Stegeman, J.J., Fleming L. E. and others: „Human Health and Ocean Pollution", *Annals of Global Health*, 86 (1), 2020, pp.151. DOI: http://doi.org/10.5334/aogh.2831. https://www.annalsofglobalhealth.org/articles/10.5334/aogh.2831/ (E-ISSN: 2214-9996)

[6] Springer, O., Springer D.: „Otrovani modrozeleni planet", Meridijani, Samobor -Zagreb, 2008. (ISBN 978-953-239-092-6)

[7] Keating, M.: "Skup o zemlji, Program za promjenu", Sektor zaštite okoliša u suradnji s Centre for Our Common Future, Ministrstvo graditeljstva i zaštite okoliša Republike Hrvatske, Zagreb, 1994, (ISBN 2-940070-00-8)

[8] Lay, V., Kufrin, K., Puđak, J.: "Kap preko ruba čaše: klimatske promjene – svijet i Hrvatska", Hrvatski centar "Znanje za okoliš", Zagreb, 2007. (ISBN 953-06656-9-8)

[9] McKibben, B.: „Smrt prirode: čovječanstvo, klimatske promjene i priroda", „The End of Nature: Humanity, Climate Change and the Natural World", Planetopija, Biovega, Zagreb, 2005. (ISBN 953-6567-99-7)

[10] Glavač, V.: „Uvod u globalnu ekologiju**"**, Hrvatska sveučilišna naklada, Ministarstvo zaštite okoliša i prostornog uređenja i Pučko otvoreno učilište, Zagreb, 2001. (ISBN 953-169-064-2)

[11] „Protecting the Marine Environment" US EPA https://www.epa.gov/international-cooperation/protecting-marine-environment

[12] "Protecting the ocean to protect humanity". https://www.conservation.org/priorities/protecting-the-ocean-to-protect-humanity

[13] "Potrebna je bolja zaštita naših mora i oceana", Europska komisija, Predstavništvo u Hrvastskoj. https://ec.europa.eu/croatia/News/potrebna_je_bolja_zastita_nasih_mora_i_oceana_hr

[14] "Okvirna direktiva o morskoj strategiji", MSFD, European Commission - Legislation: The Marine Directive. https://www.msfd.eu/knowseas/msfd.html

[15] "Okvirna direktiva o morskoj strategiji". https://era.org.mt/topic/marine-strategy-framework-directiv

[16] "Our Oceans, Seas and Coasts", The Marine Strategy Framework Directive, MSFD https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm

[17] "Mission area: Healthy oceans, seas, coastal and inland waters" https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/missions-horizon-europe/healthy-oceans-seas-coastal-and-inland-waters_en

[18] Črnjar, M., Črnjar, K.: „Menadžment održivog razvoja, Ekonomija – Ekologija – Zaštita okoliša", Fakultet za menedžment u turizmu i ugostiteljstvu u Opatiji, Sveučilište u Rijeci, Glosa Rijeka, Rijeka, 2009. (ISBN 978-959-6081-68-4)

[19] Bešker, M,: „Politika okoliša", Oskar – Centar za razvoj i kvalitetu d.o.o. Zagreb, Zagreb, 2005. (ISSN 953-6619-17-2)

[20] Črnjar, M.: „Ekonomija i politika zaštite okoliša", Ekonomski fakultet Sveučilišta u Rijeci i Glosa, Rijeka, 2002. (ISBN 953-6081-21-0)

[21] Aftić, K,: Ekološka svijest – pretpostavka rješavanja ekoloških problema, Ecological Consciousness - Pre- Condition of Solving Ecological Issues, Ekonomski pregled, Hrvatsko društvo ekonomista, vol. 53, br. 5-6, 2002, pp. 578-594. (ISSN: 0424-7558)

[22] Gelcich, S., Buckley, P., Pinnegar, J. K.: "Public awareness, concerns, and priorities about anthropogenic impacts on marine environments", PNAS Prroceedings of the National Accademy of Sciences of the United States of America 111 (42), 2014, pp 15042-15047 ISSN: 0027-8424 Internet ISSN: 1091-6490 DOI: https://doi.org/10.1073/pnas.1417344111 https://www.pnas.org/content/111/42/15042

[23] Golubić, J.: "Promet i okoliš", Fakultet prometnih znanosti, Sveučilište u Zagrebu, Zagreb, 2006. (ISBN 953-6221-99-3) https://www.weboteka.net/fpz/Ekologija%20u%20prometu/Promet%20i%20okoli%C5%A1%20-%20Knji ga.pdf
[24] Potočnjak, V., Lay, V.: "Obnovljivi izvori energije i zaštita okoliša u Hrvatskoj", Ministarstvo zaštite okoliša i prostornog uređenja RH, Zagreb, 2002. (ISBN 953-6793-17-2)
[25] Božičević, J. Matutinović, I.: „Povezanost svijeta i održivi razvoj", Hrvatska i održivi razvoj, Ministarstvo razvitka i obnove RH, Zagreb, 1998. (ISBN 953-96810-9-X)
[26] Gore, A.: "Zemlja u ravnoteži: ekologija i ljudski duh" "Earth in the balance: ecology and the human spirit", Mladost, Zagreb, 1994. (ISBN 953-1520224)

MOTOR DRIVE EXPERIMENTAL SETUP PARAMETERS DETERMINATION

Marko Zubčić
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: mzubcic@pfst.hr

Nediljko Kaštelan
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: nkastelan@pfst.hr

Maja Krčum
University of Split, Faculty of Maritime Studies
Split, Croatia
E-mail: maja.krcum@pfst.hr

Tomislav Peša

UDK 621.3:629.5

Summary

The training and practice of future marine engineers in the field of marine electrical systems in realistic conditions presents several risks, especially if the training is regarding high voltage electrical systems. In order to minimize the aforementioned risks, the training should be conducted on a simulation model that can adequately simulate the behaviour of the analysed systems so that the quality of the training is not affected. In this paper, the steady-state behaviour of an induction motor fed by a two-level voltage source inverter (2L-VSI) is investigated. Lucas-Nulle devices allow the measurement and recording of a large number of values such as voltage, current, slip, power factor, active power, reactive power, power, voltage and current frequency spectrum, modulation signal. In this work, the objective is to build a simple space vector modulation signal generator using "black box" library components in Simulink and use the measurement to validate the parameters of the inverter and induction motor. The results of the Simulink model on the motor side show good agreement with the measurement result, indicating that the motor parameters are correctly determined.

Keywords: Induction motor, Simulink model, Space Vector Modulation, Total Harmonic Distortion

1. INTRODUCTION

Training future marine engineers in realistic conditions of marine electrical systems in order to accurately analyse the behaviour of systems used on ships presents several risks (electrical shock, fire hazards…) if the proper procedures are not followed. The risks are especially high if the training field are high voltage electrical systems. In order to minimize the risks, the analysis of system should be performed on simulation models who offer accurate behaviour of the simulated systems. The simulation models of the most used component on the ship, the electric motor, have the advantage of analysing and changing of multiple parameters without the presence of hazardous voltages in order to determine the ones who best suit the required working conditions. Simulation models can consist of the motors alone and also on the components required to drive the motor.

In this paper, the steady-state behaviour of an induction motor fed by a two-level voltage source inverter (2L-VSI) is investigated. The devices used for the investigation are the two-level inverter and the induction motor from the motor drive training program of the company Lucas-Nulle. The experimental setup is shown in Figure 1.

The Lucas-Nulle equipment allows the measurement and recording of a large number of values such as voltage, current, slip, power factor, active power, reactive power, voltage and current frequency spectrum, modulation signal. There is also the possibility to select different predefined load characteristics (flywheel, pump...) and to define the load characteristics by the user (through mathematical functions and graphic interface). All mentioned options provide tools for small scale analysis of electrical drives [1].

There are a large number of simulation models for 2L-VSI fed induction motors in the literature [2,3,4]. In this work, the objective is to build a simple space vector modulation signal generator using "black box" library components in Simulink and use the measurement to validate the parameters of the inverter and induction motor.

In this paper, the parameter and Simulink model validation is studied only for the frequency of 50 Hz. For Lucas-Nulle devices, there is a choice of different modulation types. In this paper, the space vector pulse width modulation (SVPWM) is used. In comparison, SVPWM is superior to sine pulse width modulation (SPWM) in terms of more effective utilization of DC link voltage, current Total Harmonic Distortion (THD), smooth speed response and torque ripple reduction [5,6].

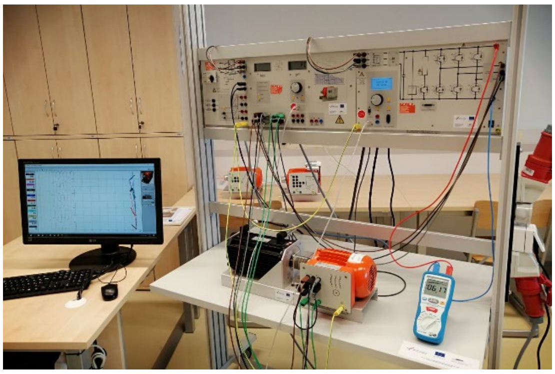


Figure 1 Motor drive experiment setup

Source: Authors

2. DETERMINATION OF SIMULINK MODEL PARAMETERS

The parameters of the asynchronous motor Lucas-Nulle SE2673-1K are given by the device manufacturer (Table 1). The model of the asynchronous motor selected in the Simulink environment is Asynchronous Machine, which is located in the Simscape library (Specialized Power Systems sublibrary).

The following parameters must be determined for the model (as specified in the model description):

- Rated power, voltage (line-line) and frequency (Pn,Vn,fn).
- Stator resistance and leakage inductance (Rs, Lls)
- Rotor resistance and leakage inductance (Rr', Llr')
- Magnetizing inductance (Lm)
- Combined rotor and load inertia coefficient (J)
- Combined rotor and load viscous friction coefficient (F)
- Pole pairs (p

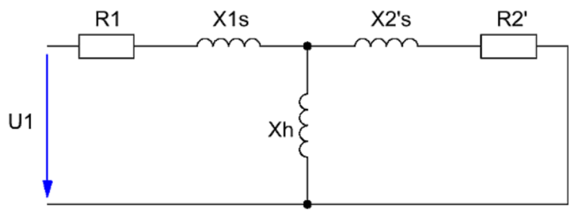
Table 1 Induction motor parameters - as stated by the manufacturer

Motor type	SE2673-1K
Rated power	370 W
Rated voltage (Y)	400 V
Rated current (Y)	1.2 A
Rated frequency	50 Hz
Rated speed	1380 rpm
Power factor	0.76
Mass moment of inertia	$7\cdot10^{-4}$ kgm^2
R1 phase resistance (20℃)	20.46 Ω
X1s stator reactance	27.24 Ω
R2' rotor resistance (20℃)	15.72 Ω
X2's rotor reactance	27.24 Ω
Xh magnetizing reactance	409 Ω
Lh magnetizing inductance	1.3 H

Source: Lucas-Nulle datasheet

Equivalent circuit diagram of the motor SE2673-1K is shown in Figure 2.

Figure 2 Equivalent schematic of induction motor



Source: Lucas-Nulle LabSoft

It can be seen that all parameters except the coefficient of friction are given by the manufacturer. In order to investigate the agreement of the model with the real induction motor, the first step was to load and carrie out the measurements on the motor. The second step was to replicate the setup in the Simulink environment using the parameters from Table 1. The correction was made for the inertia factor J due to the coupling with the servo machine. The inertia factor in the model is the sum of the inertia factor of the induction motor (7-10-4 kgm2) and the inertia factor of the servo machine (8.3-10-4 kgm2). The elements of the structure are the power supply, the induction motor coupled to the servo machine, and the control/measurement unit. The servo machine is controlled by the control/measurement unit.

With the servo machine, the load was set at 1 and 2 Nm. Because of the discrepancy between simulation and measurement results, only two load points were considered. For each load point, 40 measurements of all values were taken. The Simulink model is shown in Figure 3. The simulation results and measurements averaged over 40 points are shown in Table 2.

Table 2 Simulation and measurement results

U=425.13 [V]		M_{Load}=1 [Nm]		Diff. [%]
		Simulink	Measurement	
I	[A]	0.60	0.73	17.74
Pel	[W]	179.50	259.94	30.96
Pm	[W]	154.50	156.63	1.36
U=423.54 [V]		M_{Load}=2 [Nm]		Diff. [%]
		Simulink	Measurement	
I	[A]	0.74	0.88	16.53
Pel	[W]	347.8	449.85	22.68
Pm	[W]	303.4	305.87	0.81

Source: Authors

Changing the coefficient of friction F from 0 to 0.01 in fixed steps did not produce an overall agreement between the simulated and measured results.

The discrepancy in the results is due to the neglect of iron losses, lack of information on the coefficient of friction for the motor and the setup itself. The manufacturer does not provide information about iron losses and consequently the equivalent resistance value RFe (Figure 2). The Simulink model does not require the RFe parameter. The manufacturer does not provide information about the friction coefficient, which is needed in the Simulink model. The problem with the setup itself is the lack of information about the friction losses of the servo machine, which must be added to the friction losses of the induction motor. To overcome this problem for the model, the no-load and blocked rotor test were performed according to [7,8]. The first step with the measured data was to determine the parameters of the induction motor (coupled with the servo machine) and the second step was to compensate for the iron losses.

The results of the blocked rotor and at no load are shown in Table 3 together with the calculated motor parameters.

Table 3 Results of No-Load / Blocked rotor testing and calculated motor parameters

f=50 [Hz]		Blocked rotor	No-load
U	[V]	424.82	418.62
I	[A]	4.22	0.67
cos(φ)	[ ]	0.7998	0.1922
Pel	[W]	2482.38	93.25
Parameters			
R_S	[Ω]	27.9	
R_r'	[Ω]	18.6	
$L_{σS}$	[H]	0.056	
$L_{σr}'$	[H]	0.056	
L_m	[H]	1.09	
J	[kgm^2]	0.00153	

Source: Authors

Friction and ventilation losses were not measured because the measurement setup does not include a 3-phase variable transformer. Thus, to determine the proper behaviour of the inductor with the model, the iron losses were added to the friction and ventilation losses. For the no-load test, the friction constant F is calculated as follows:

$$P_{Fe} + P_{fr,v} = P_0 - P_{CuS} \quad (1)$$

$$P'_{fr,v} = Fw_0^2 = P_0 - P_{CuS} \quad (2)$$

$$F = 0.0023 \text{ Nms} \quad (3)$$

In order to verify the compliance of the model in the range of nominal torque, three measurements were performed. The results are shown in Table 4.

Table 4 Simulation, results with applied parameters from Table 3, and comparison to measurement in 3 load point

U=425.13 [V]		M_{Load}=1 [Nm]		Diff. [%]
		Simulink	Measurement	
I	[A]	0.734	0.735	0,13
Pel	[W]	257.7	259.94	0,86
Pm	[W]	152.9	156.63	2,49
Q	[VA]	475.6	474.95	-0,13
n	[rpm]	1460	1465.67	0,38
U=423.54 [V]		M_{Load}=2 [Nm]		Diff. [%]
		Simulink	Measurement	

I	[A]	0.868	0.886	2,03
Pel	[W]	443.6	449.85	1,38
Pm	[W]	298.7	305.87	2,34
Q	[VA]	469.24	469.85	0,12
n	[rpm]	1426	1424.82	-0,08
U=423.6 [V]		M_{Load}=2.56 [Nm]		Diff. [%]
		Simulink	Measurement	
I	[A]	1.00	1.00	0
Pel	[W]	559.8	562.23	0,43
Pm	[W]	375.3	373.74	-0,41
Q	[VA]	478.8	479.25	0,09
n	[rpm]	1400	1394.4	-0,40

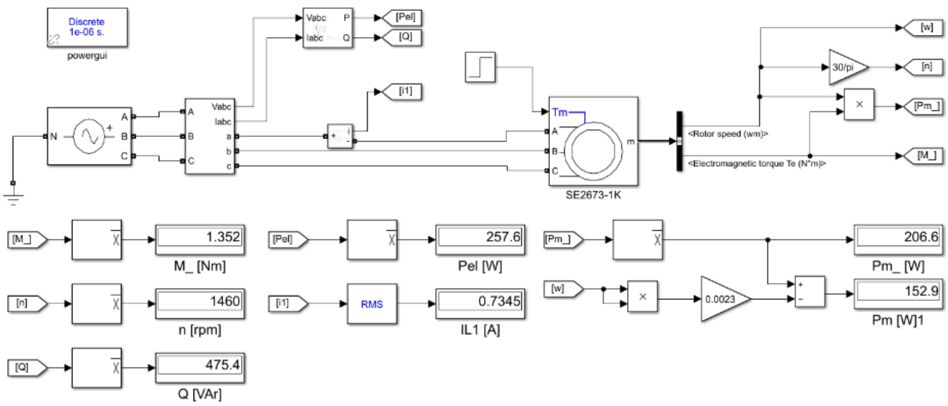


Figure 3 Simulink model of induction

Source: Authors

3. INVERTER MODEL

Lucas-Nulle self-commutated converter offers different modulations with the ability to change the carrier frequency. CO3636-3B Lucas-Nulle module (Figure 4) modulation types are: SVPWM, SVPWM line, SPWM with 3rd harmonic injection, SPWM and block. There are 3 carrier frequencies: 8, 4 and 1 kHz. In this paper, a SVPWM Simulink model is created with a carrier frequency of 8 kHz.

The model is built using a "black box" approach. Measurements are made using module CO3636-3B to validate the model in steady state. Lucas-Nulle CO3636-6V measurement module has been placed between the motor and the inverter.

In the model, the dU/dt filter is omitted. The data sheet does not contain technical details of the filter (topology, parameters). There is also no technical information about mains filter. The mains filter is modelled as an air coil and its inductance is tuned by the trail-and-error method according to the value of the reactive power measurement on the motor side. The inductance of the air coil is set to 0.3 H. The same procedure is applied to the DC link capacitor. The capacitance is set to 200 μF. The Simulink model of the inverter is shown in Figure 5 and the SVPWM signal generator is shown in Figure 6.

Measurements are made for the torque range 0 - 2.56 Nm in increments of 0.06 Nm. For each step, 5 measurements of each value were taken and averaged for data presentation.

The measured values are active power before the inverter (Pel1), reactive power before the inverter (Q1), active and reactive power after the inverter (Pel2, Q2), motor speed, motor phase current L1 (IL1) and shaft power (Pm). The simulation was performed for the torque range 0 - 2.56 Nm in steps of 0.25 Nm (11 points in total).

Simulation and measurement results are shown in Figures 7,8,9,10,11,12,13. The maximum difference found between the Simulink results and the measurement is given in the figures.

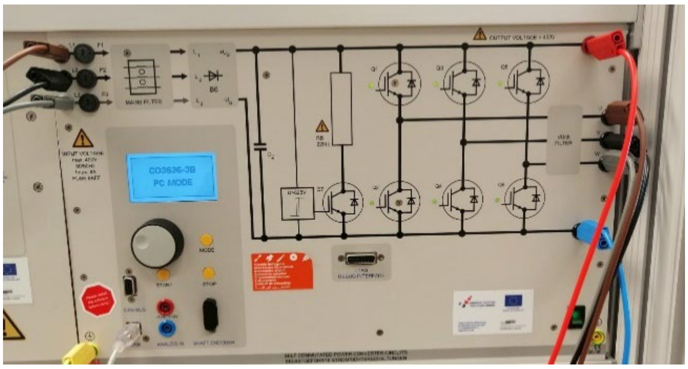


Figure 4 CO3636-3B module

Source: Authors

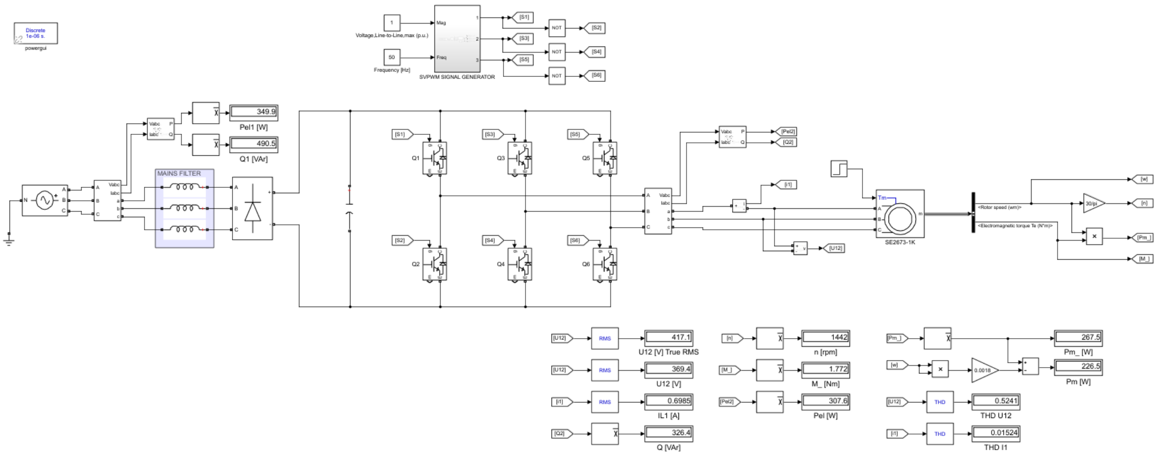


Figure 5 Simulink model of the experimental setup

Source: Authors

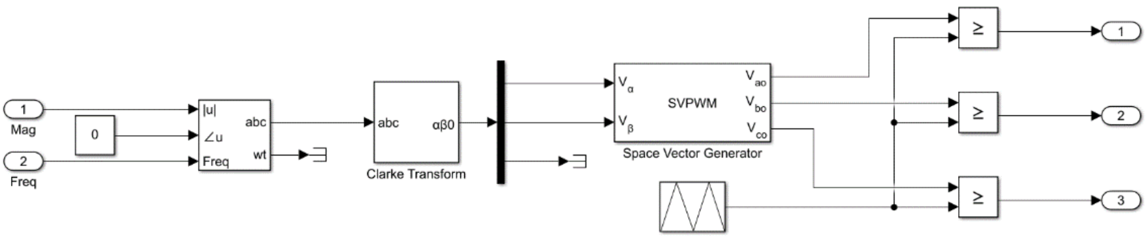


Figure 6 Simulink SVPWM signal generator

Source: Authors

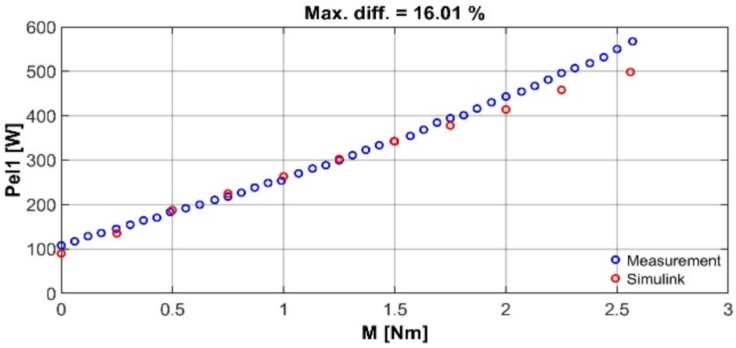


Figure 7 Electrical power Pel1 – torque dependence

Source: Authors

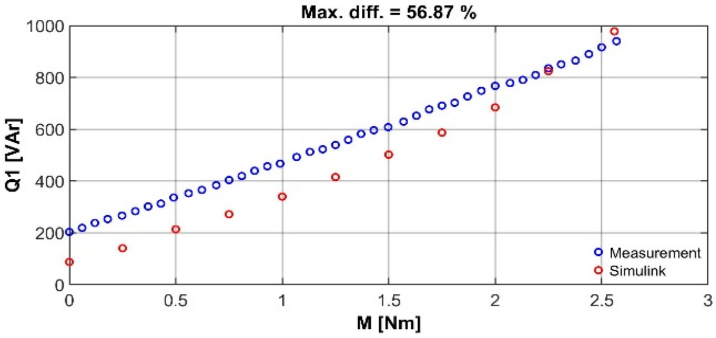


Figure 8 Reactive power Q1 – torque dependence

Source: Authors

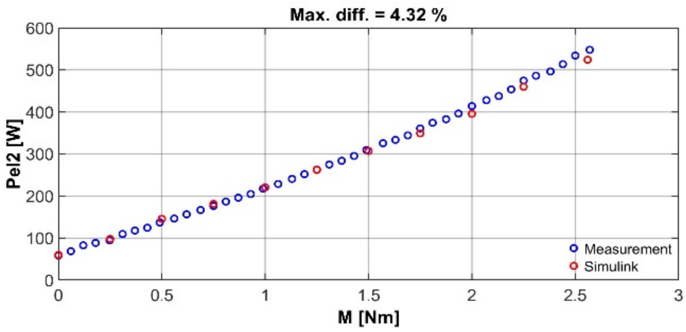


Figure 9 Electrical power Pel2 – torque dependence

Source: Authors

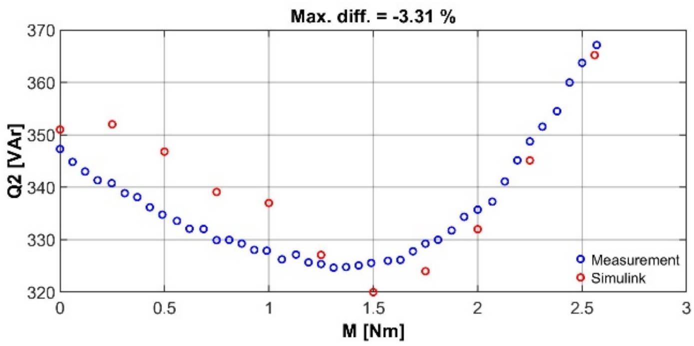


Figure 10 Reactive power Q2 – torque dependence

Source: Authors

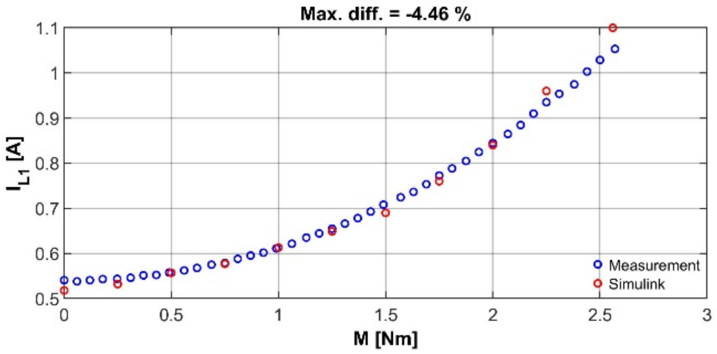


Figure 11 Line current IL1 – torque dependence

Source: Authors

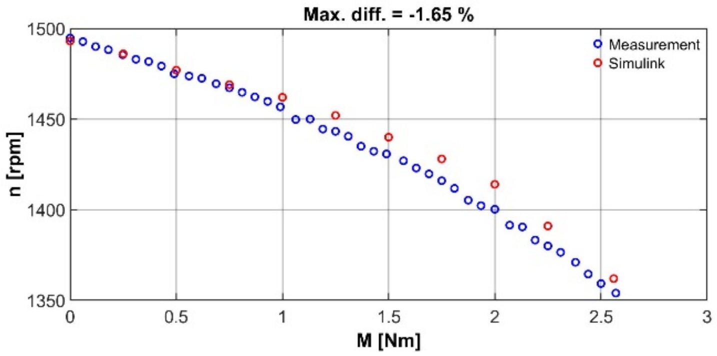


Figure 12 Line current IL1 – torque dependence

Source: Authors

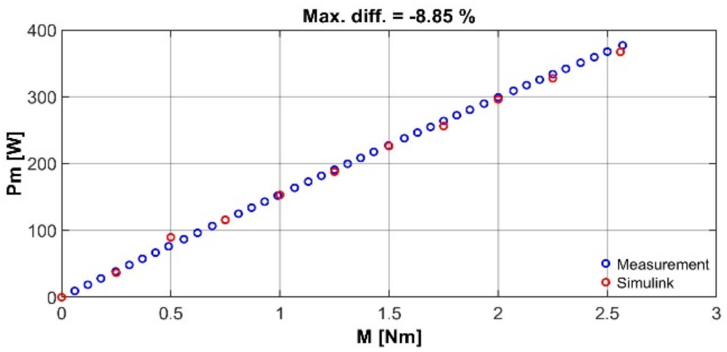


Figure 13 Mechanical power Pm – torque dependence

Source: Authors

4. THD

The CO3636-3B module and the LabSoft software can be used to record and evaluate current and voltage waveforms. The LabSoft interface with the display of the phase current L1 and line voltage U12 is shown in Figure 14 and Figure 15. The frequency spectrum of the line current IL1 and line voltage U12 is exported from LabSoft to Matlab, where the THD of current and voltage is calculated.

THD results obtained with LabSoft and Simulunk THD results are presented in Table 5.

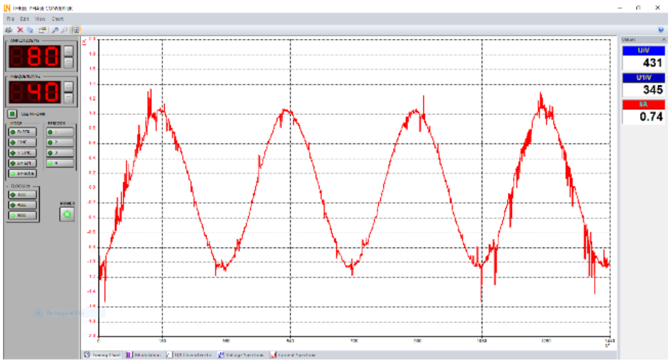


Figure 14 Line current IL1 waveform

Source: Authors

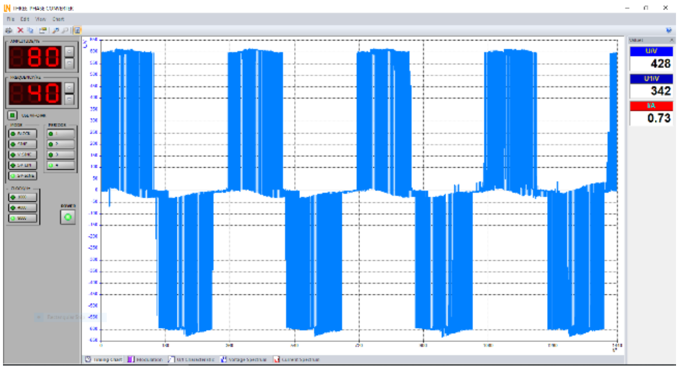


Figure 15 Line voltage U12 waveform

Source: Authors

Table 5 LabSoft and Simulink THD results

f=50 [Hz]		M = 2 [Nm]		M = 2.56 [Nm]	
		Sim.	LabS.	Sim.	LabS.
THD IL1	[%]	1.16	6.84	0.87	6.68
THD U12	[%]	52.42	51.75	52.42	52.5

Source: Authors

4. CONCLUSION

The results of the Simulink model on the motor side show good agreement with the measurement results, indicating that motor parameters were correctly determined, validating that the used model offers real life system behaviour for a quality and safely performed training. The presented model and the results can be used in the process of determining the optimal motor for use in the specified conditions which will yield an approach to choose the adequate component in the marine electrical system, that can meet the requirements to be met by the increasingly complex electric motor drives on board. In the simulation the discrepancy of the results appears for the input reactive power to the inverter (Q1) and THD of the line current IL1. The first reason is the dU/dt filter, which was omitted from the model due to missing information (topology and parameters of the filter). The same is true for mains filter, which is modelled as an air coil. The second reason is the ideal switching of the IGBT's in the Simulink model (dead time effect is not considered)

The focus of future work will be to determine the parameters of the inverter subcomponents (mains and dU/dt filters).

Acknowledgments

This research paper would not be possible without the project "Functional integration of the University of Split, PMF / PFST / KTF through the development of scientific and research infrastructure in the three faculty (3F) building (KK.01.1.1.02.0018)".

REFERENCES

[1] Nell, M., Lenz, J. and Hameyer, K. „Scaling laws for the FE solutions of induction machines". In: Archives of electrical engineering, 68 (3), 677-695, 2019 DOI: 10.24425/AEE.2019.129350

[2] Kriti Agrawal, Abhay Gandhi, M.T. Shah, M.V. Gojiya, "Design, Analysis and Realization of SVPWM using Embedded Code Generation Technique for a Three Phase, Two Level Inverter", IEEE International Conference on Electrical Power and Energy Systems, MANIT, Bhopal, December 2016. DOI: 10.1109/ICEPES.2016.7915961

[3] A. Mansouri and K. Benabdallah, "Experimental analysis of the space vector PWM control of two-level inverter to feeding an induction motor," *2017 International Conference on Electrical and Information Technologies (ICEIT)*, 2017, pp. 1-6, doi: 10.1109/EITech.2017.8255283.

[4] S. Singh and A. N. Tiwari, "Analysis and simulation of vector controlled PMSM drive using SVPWM inverter," *2017 2nd International Conference for Convergence in Technology (I2CT)*, 2017, pp. 709-714, doi: 10.1109/I2CT.2017.8226221.

[5] J. Sabarad and G. H. Kulkarni, "Comparative analysis of SVPWM and SPWM techniques for multilevel inverter," *2015 International Conference on Power and Advanced Control Engineering (ICPACE)*, 2015, pp. 232-237, doi: 10.1109/ICPACE.2015.7274949.

[6] M. N. Gujjar and P. Kumar, "Comparative analysis of field oriented control of BLDC motor using SPWM and SVPWM techniques," *2017 2nd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)*, 2017, pp. 924-929, doi: 10.1109/RTEICT.2017.8256733.

[7] France O. Akpojedje, Ese M. Okah, Yussuf O. Abu."A Comparative Analysis of Three Phase Induction Motor Performance Evaluation".International Journal of Engineering and Techniques (IJET) V2(3): Page(64-75) May - June 2016. ISSN: 2395-1303. www.ijetjournal.org. Published by International Research Group- IRG. ISSN: 2395-1303

[8] I. Mitran, A. Bitoleanu and M. Lincă, "Induction motor parameters determination for iron losses analysis," 2012 International Conference on Applied and Theoretical Electricity (ICATE), 2012, pp. 1-6, doi: 10.1109/ICATE.2012.6403428.